1982

Distribution, Movement, and Temperature Selection of Adult Walleye and Muskellunge in a Power Plant Cooling Reservoir

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DISTRIBUTION, MOVEMENT, AND TEMPERATURE SELECTION OF ADULT WALLEYE AND MUSKELLUNGE IN A POWER PLANT COOLING RESERVOIR

BY

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A thesis submitted
in partial fulfillment of the requirements
for the degree, Master of Science, Major
in Wildlife and Fisheries Sciences
Fisheries Option
South Dakota State University
1982

DISTRIBUTION, MOVEMENT,
AND TEMPERATURE SELECTION
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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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ACKNOWLEDGMENTS

My sincere thanks go to Dr. R. L. Applegate for his help and encouragement throughout the study. Special thanks to Dr. C. G. Scalet, Dr. W. L. Tucker, and T. C. Modde for their criticism and assistance during the preparation of this thesis.

I would like to thank the following people for assistance during the study: N. N. Thomas, Otter Tail Power Co., provided access and facilities at the cooling reservoir; South Dakota Department of Game, Fish, and Parks personnel for supplying the fish; and fellow graduate student G. A. Raisanen for his field assistance.

Finally, very special thanks are extended to Diane (Younk) Olson for her patience and understanding in the typing of this thesis and to my parents, without whose understanding and moral support this thesis could not have been completed.

Financial assistance was provided by the South Dakota Cooperative Fishery Research Unit[1] through Dingell-Johnson Project F-15-R and the South Dakota University Agricultural Experiment Station.

[1]Cooperating agencies: South Dakota Department of Game, Fish and Parks, South Dakota State University and United States Fish and Wildlife Service.

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Abstract

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Distribution and habitat selection of five adult walleyes (*Stizostedion vitreum vitreum*) and one adult muskellunge (*Esox masquinongy*), in a power plant cooling reservoir, were determined using temperature-sensitive ultrasonic transmitters. A total of 342 locations were obtained during the monitoring period (1 May-13 November 1981).

Walleyes exhibited a seasonal distribution pattern; inhabiting the discharge area during the cooler months and the intake area during the warmer months. Summer-fall home ranges of three walleyes were estimated. Maximum home ranges (maximum area covered by an individual) were overlapping and similar in size, ranging from 36.7-45.9 ha. Estimates of utilized areas (intensively used portions of the maximum home range) represented less than 38% of the maximum home range of individuals. From May to July most walleye locations were concentrated along the shoreline (sloping rip-rapped areas) in water 2.0-4.0 m deep. During late summer and early fall walleyes moved to progressively

deeper, offshore areas. Mean daily distance moved peaked during June (186.8 m) followed by declines during July and August (124.3 m and 112.7 m, respectively). Fall movement rates fluctuated, averaging 129.3 m/day during September and November, and 65.5 m/day in October. Walleye body temperatures ranged from 7.0° C in October to 30.0° C in July. The most frequent body temperature recorded was 25.0° C.

The muskellunge was considerably more active than the walleyes. From June to July an area of approximately 10.4 ha was utilized by the muskellunge. The fish inhabited offshore areas with water depths of 4.0-7.5 m. Average daily movement of the muskellunge increased from 125.3 m during May to 278.1 m during July. Mean body temperatures ranged from 21.8° C in May to 27.0° C in July. Seventy-two percent of all body temperatures recorded were 25.0° C. From 9 July-24 July, 59 muskellunge including the tagged muskellunge, were found dead. The last recorded body temperature of the tagged muskellunge (4 July) was 27.0° C. Mean water temperature at the intake and mixing areas during the die-off period ranged from 29.3° C (bottom) to 30.2° C (surface) and 27.5° C (bottom) to 32.4° C (surface), respectively.

Water temperatures ranged from 6.5-42.5° C over the entire period. Highest water temperatures recorded occurred in July, averaging 32.6° C in the discharge area and 27.3° C in the intake area. Dissolved oxygen concentration ranged from 0.0 to 12.5 mg/l. Secchi disk visibility never exceeded 2.0 m during the study.

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INTRODUCTION

The amount of electricity produced in the United States has doubled every 10 years since 1945, and the outlook for the future indicates even greater increases (Krenkel and Novotry 1980). With this expansion in electrical generation will come increases in the use of water as a cooling source.

In 1970, the power industry used approximately 10% of the total flow of United States rivers and streams for cooling purposes (Dallaire 1970). By 1980, this volume was expected to reach 20% of the total freshwater flow (Dallaire 1970), and by the year 2000, approximately 33% of the average daily freshwater runoff in the United States may be needed for once-through cooling (Clark 1969). Ultimately this leads to considerable increases in heat released into the aquatic environment.

However, with the use of accessory cooling facilities as alternatives to once-through cooling, excess heat can be disposed of without impacting natural waterways. One type of cooling system most likely to be used is the cooling pond, lake, or reservoir (Meredith 1973; Metz 1977). This type of system is designed for dissipation of heat as water travels from discharge to intake, after which the cool water is recirculated through the plant. In addition, with proper design and management, these man-made bodies of water can be utilized for other purposes such as flood control, recreation, and aquaculture (Metz 1977).

In 1972, a cooling reservoir was constructed at Big Stone Power Plant in South Dakota. Although the primary purpose of the reservoir was to insure zero discharge of heated water into natural waterways, it also provided a potential fish rearing facility. Studies were begun in 1978 to evaluate the cooling reservoir for use as a game fish brood stock development area. Initial studies were concerned with monitoring physicochemical conditions and evaluating the forage base in the reservoir (Wheeler 1979; Johnson 1980; Sloane 1980; Wahl 1980). Further studies dealt with feeding ecology, growth, and distribution of fishes (Krska 1980; Wahl 1980; Henley 1981).

Distribution and movement of fishes depends on a number of factors which include: chemical parameters, habitat characteristics, availability of forage, and competition. However, when dealing with a thermally altered body of water, temperature has been regarded as the most prominent factor influencing fish distribution. Numerous studies have been conducted in an attempt to assess the effects of temperature on the distribution and behavioral thermoregulation of fishes in artificially heated lakes and reservoirs (Dryer and Benson 1956;

Barkley and Perrin 1971; Bennett 1971; Smith 1971; Holland et al. 1974; McNeely and Pearson 1974; Neill and Magnuson 1974).

Temperature plays a key role in determining the physiological and biochemical rates of fish (Fry 1971). Because fish are poikilothermal, their body temperature depends on the temperature of the surrounding water (Brett 1956). Thus, fish tend to seek thermal ranges that optimize their chances of growth, survival, and reproduction. Variation in water temperatures outside the range for which fish are adapted could alter their chances of maintaining a viable population.

The purposes of this study were: (1) to determine the distribution and movement of adult walleye (*Stizostedion vitreum vitreum*) in a power plant cooling reservoir, (2) to determine temporal changes in body temperatures of adult walleye, and (3) to assess the ability of adult walleye to survive high temperatures. Although I was primarily interested in walleyes, information was also collected on one muskellunge (*Esox masquinongy*).

STUDY AREA

The Big Stone Power Plant is located in northeastern Grant County, South Dakota (45° 18'N, 96° 30'W). The coal-fired 440 MW steam electric generating facility is owned jointly by Montana-Dakota Utilities Company, Northwestern Public Service Company, and Otter Tail Power Company. The cooling reservoir consisting of a compacted clay bottom and a granite rip-rap baffle dike and encompassing levee, was completed in 1972. The Big Stone Power Plant began operating in May 1975 and has the capacity of circulating water from the cooling reservoir through its main condenser at a rate of 509.7 m^3/min.

The cooling reservoir, which has an average surface area of 145 ha, maximum depth of 10 m, and mean depth of 4.9 m, is divided by a T-shaped dike (Fig. 1). The intake is located on the east side of the dike and the heated water is discharged on the west side of the dike; the area between serves as a mixing zone. Reservoir water level is maintained by drawing water from nearby Big Stone Lake.

Various physical, chemical, and biological characteristics of the cooling reservoir have been reported by Wheeler (1979), Johnson (1980), Krska (1980), Sloane (1980), Wahl (1980), and Henley (1981). The cooling reservoir is alkaline (pH 7.4-9.1, alkalinity 105-170

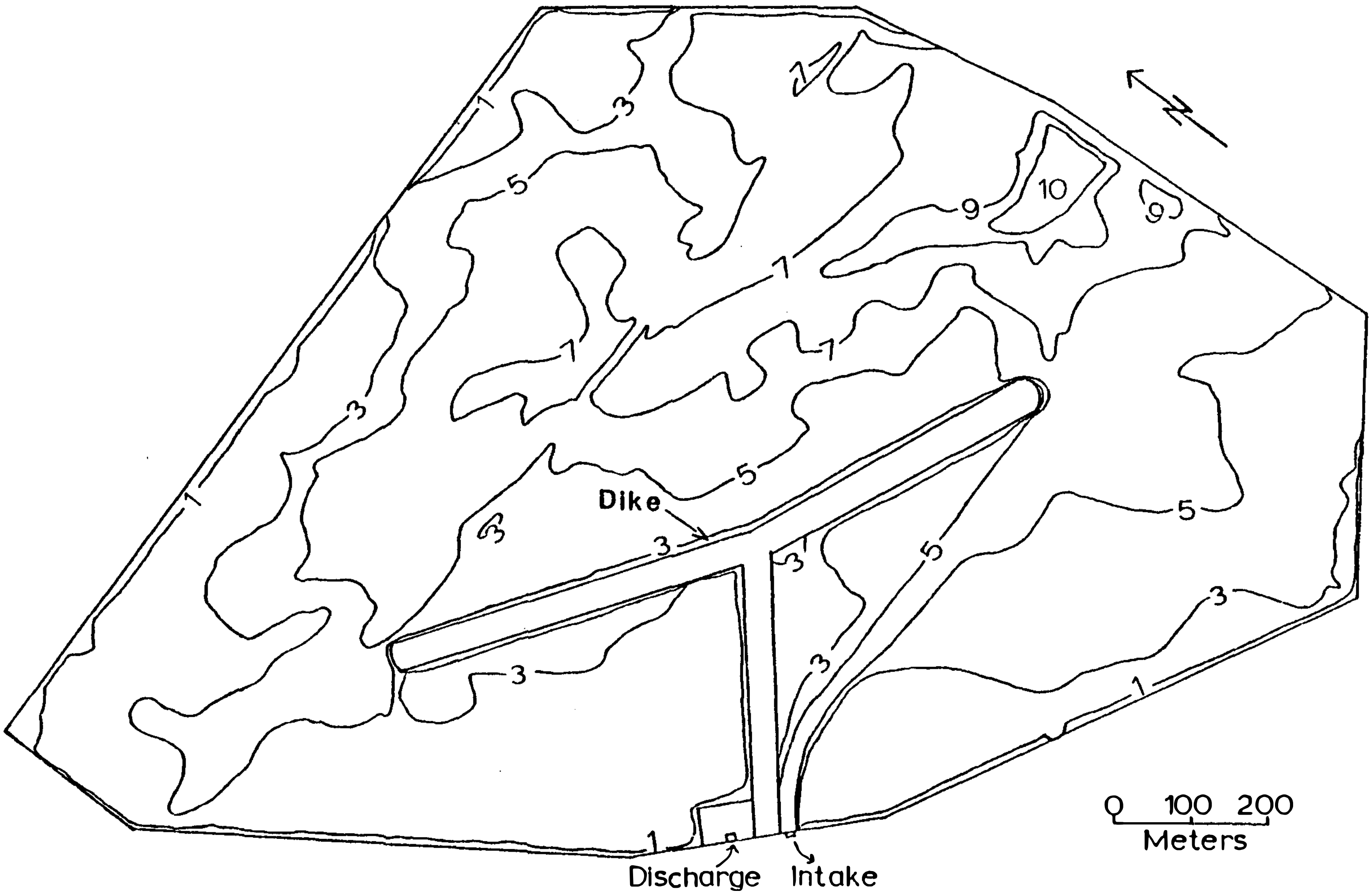

Fig. 1. Big Stone Power Plant cooling reservoir, South Dakota, with depth contours (m) shown (341.1 m above mean sea level).

mg/l $CaCO_3$) and highly conductive (specific conductance 1609-4137 micromhos/cm). Reservoir temperatures ranged from 0.0-42.0° C and dissolved oxygen values ranged from 0.0-15.6 mg/l. The fish community consists of 18 species of forage fish, introduced during periods of reservoir filling; muskellunge were stocked from 1978-1981 and walleyes were stocked in 1982.

METHODS

Telemetry equipment used in this study was commercially manufactured by Donald L. Brumbaugh, Tucson, Arizona. The temperature sensitive ultrasonic transmitters were 60.0 mm long, 16.0 mm in diameter, and weighed 8.0g in water. Each transmitter operated at a separate output frequency that ranged from 75.2-104.4 khz. Pulse rate (seconds/10 pulses) varied within each frequency in direct relation to temperature. Calibration curves determined in the laboratory were used to convert pulse rates to corresponding temperatures.

Signals emitted by a transmitter were received by a hand-held, directional hydrophone connected to an ultrasonic receiver capable of detecting frequencies from 70-110 khz. Headphones and a stopwatch were used to detect signals and determine pulse rates.

Walleyes utilized for the telemetry study were captured with trap nets in Big Stone Lake (1 April 1981). After fish were stripped of eggs or milt, they were placed in a holding tank and transported to the cooling reservoir. The single muskellunge tagged was captured in the cooling reservoir (11 March 1981) by seining with a gill net.

Nine walleyes (1.8-3.0 kg) and one muskellunge (3.1 kg) were surgically implanted with ultrasonic transmitters with methods described by Hart and Summerfelt

(1975) and Crossman (1977). The fish were anesthetized in 15.0 mg/l quinaldin solution and held ventral surface up in an oval tub. A 20-30 mm incision was made approximately 50 mm anterior to the anus (anterior to the pelvic girdle in the muskellunge). Each transmitter was treated with a 10% ethyl alcohol rinse followed by a 15% terramycin-water solution before inserting it anteriorly into the body cavity. The incision was closed using a half circle, cutting edge needle trailing 4-0 braided silk. Three to four sutures, each consisting of 3 surgeon's knots, were made at approximately 5.0 mm intervals. Post-operative fishes were treated with terramycin powder, placed in a recovery tank for 15-20 minutes, and then released into the intake area of the reservoir.

The monitoring period began 1 May 1981 and continued until all transmitters had ceased functioning. Fish were located three to five days each week during June, July, and August and two to three days each week during May, September, October, and November. Fish location was determined by triangulation on shore landmarks with a sextant. Once located, pulse rate, time of day, date, and substrate type (rip-rap or clay) were recorded. In addition maximum depth, temperature profile, and Secchi disk visibility were measured.

Temperature, dissolved oxygen, and Secchi disk visibility were monitored at 10 stations positioned throughout the reservoir (Fig. 2). Temperature profiles were recorded with a YSI Model 33 S-C-T meter prior to each daily tracking period. Dissolved oxygen values were obtained once a week during May and June and one to two times a month during the remainder of the study. Due to equipment failure, dissolved oxygen values were not recorded during September. Dissolved oxygen determinations were made with a YSI Model 54 oxygen meter and by the modified azide-Winkler method. Visibility was estimated using a 20 cm in diameter Secchi disk.

Maps of the reservoir were prepared with a grid system on which squares represented 6.7 m^2. Fish locations were plotted on the gridded maps and assigned X-Y coordinate values. These points were used to determine home range and mobility parameters.

Burt (1943) described home range as that area over which the individual normally travels including areas of food gathering, mating, and rearing young. By definition this would include the time span from one mating season to the next, which for most animals in temperate regions encompasses one year. However, it was also pointed out that individuals do not always occupy the same area, often abandoning one home range and setting up another. During the course of a year, the walleyes may well use

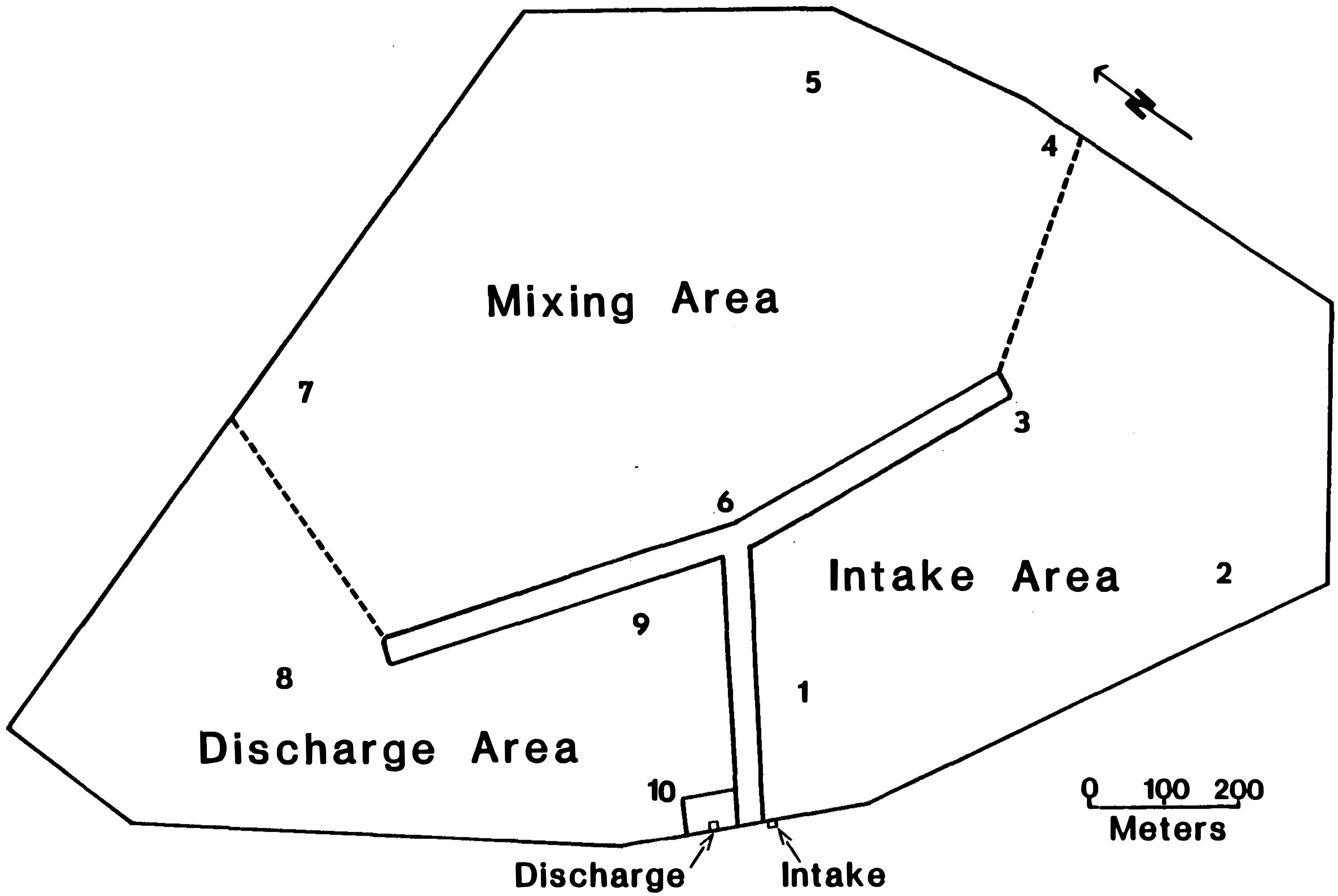

Fig. 2. Locations of the physicochemical monitoring stations with reference to the three main areas in Big Stone Power Plant cooling reservoir.

the entire reservoir, as was established for muskellunge (Henley 1981), however, for the purposes of this study home range was defined as that area traversed during the summer-fall (June to November) time period. This time period was determined according to the pattern of fish movement rather than calendar time.

Maximum home range (maximum area covered by an individual) and utilized home range (intensively used portions of the maximum home range) were estimated (Odum and Kuenzler 1955). Maximum home range was determined by the convex polygon method (Winter's 1977 modification of Odum and Kuenzler 1955). The extreme outermost locations plotted were connected with straight lines encompassing all other locations. If a side of the polygon cut across land, the shoreline was used as a boundary. The proportion of the maximum area utilized, termed utilized or primary home range (Winter 1977), was determined by the grid square method (Rongstad and Tester 1969). Area of the squares and number of locations in each square were summed to determine utilized home range and intensity of use, respectively. Squares without locations were included in the utilized home range estimate provided the number of empty squares between two adjacent locations, vertically or horizontally, did not exceed a designated number (Rongstad and Tester 1969; Winter 1977). Einhouse (1981) was used to determine this designated number. The geometric centers of home range were calculated as the mean X and Y coordinate values for all locations (Hayne 1949). Distances from each location to the geometric center of home range were measured (Dice and Clark 1953) and their frequency distribution presented as described by Tester and Sniff (1965) and Ables (1969).

Movement rates were estimated by measuring the total distance between consecutive locations. If two locations were separated by the T-dike, distances were estimated by measuring the shortest distance around the dike. These distances were summed and divided by the number of days an individual was tracked and expressed as a daily distance moved. This value represented the minimum distance traveled.

Statistics used in body temperature analyses were mean, mode, range, and frequency distribution. A Chi-square test (P=.05) was used in comparing the number of observed and expected locations in relation to the proportion of available acreage within each depth category.

RESULTS

Of the 10 fish tagged, 3 walleyes died within a week after release and 1 walleye was lost due to an inactive transmitter. A total of 342 locations were obtained over a 28 week period (300 locations for 5 walleyes, 42 locations for the muskellunge) (Table 1).

Distribution of Walleye

Since the walleyes were transplanted from Big Stone Lake into new surroundings, the fish were allowed a one month adjustment period. During this period walleyes were monitored on an irregular basis, and the data were excluded from analysis. Post-surgical behavior was initially characterized by quiescent periods in deep water regions of the intake area, followed by increased movement and dispersal.

The walleyes exhibited a distinct seasonal distribution pattern; inhabiting the discharge area during the cooler months and the intake area during the warmer months (Fig. 3). Although walleyes were released in the intake area, only two locations (12%) were recorded in that area during May. Most walleyes gravitated toward the northwest end of the reservoir (Fig. 4), concentrating along the periphery of the discharge area at water temperatures ranging from 18.0-26.0° C. The fish avoided areas within the immediate vicinity of the discharge outlet, particularly

Table 1. Tracking history of one muskellunge (*Esox masquinongy*) and nine walleyes (*Stizostedion vitreum vitreum*) in Big Stone Power Plant cooling reservoir, May-November 1981.

Species	Tag No.	Total length (mm)	Weight (kg)	Sex	Initial contact	Date of last contact	Monitoring period (Days)	No. of contacts
Muskellunge	75.2	780	3.1	-	1 May	4 July	65	42
Walleye	78.2	632	2.6	F	1 May	1 May	0	0
Walleye	81.2	584	2.0	F	1 May	16 October	169	83
Walleye	84.6	661	3.0	F	1 May	13 November	197	88
Walleye	87.4	554	1.8	M	1 May	2 November	186	77
Walleye	90.2	598	2.1	F	1 May	17 July	78	18
Walleye	93.0	592	2.1	M	1 May	1 May	0	0
Walleye	97.0	572	1.8	F	1 May	1 May	0	0
Walleye	99.2	630	2.5	M	1 May	26 June	57	34
Walleye	104.4	580	1.8	F	1 May	1 May	0	0

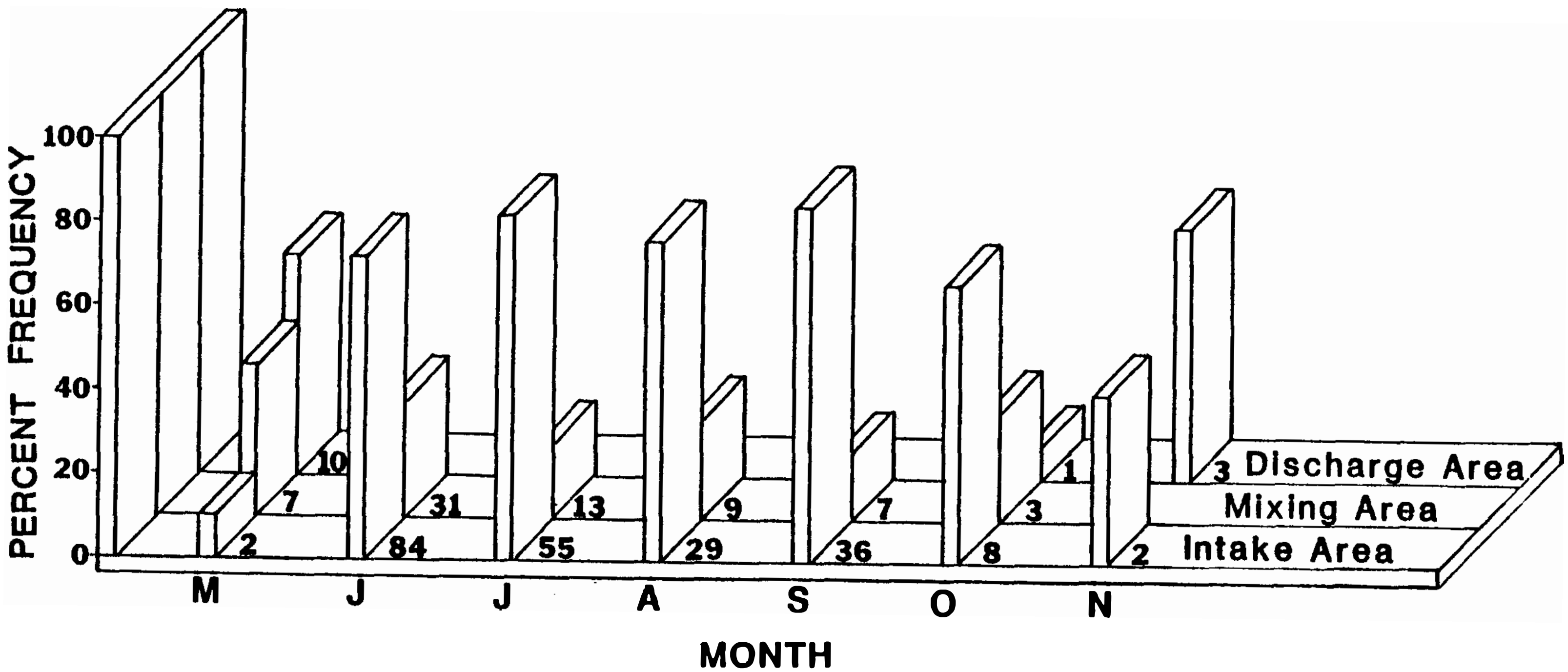

Fig. 3. Distribution of adult walleyes (Stizostedion vitreum vitreum) in relation to the thermal gradient demonstrated by changes in frequency of locations of the fish between the established areas in Big Stone Power Plant cooling reservoir, May-November 1981. The numbers in the chart represent the actual number of observations.

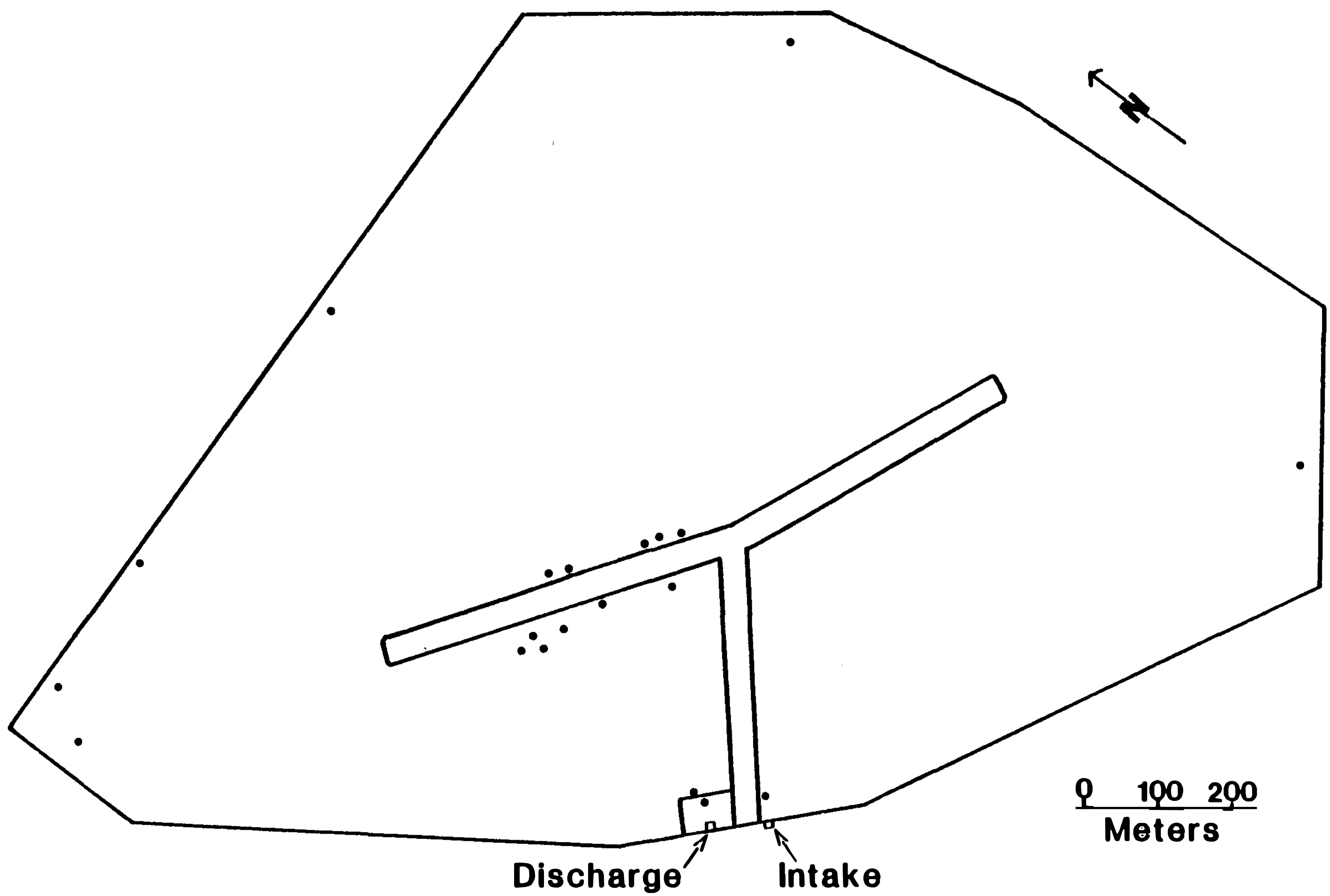

Fig. 4. Locations of adult walleyes (*Stizostedion vitreum vitreum*) monitored in Big Stone Power Plant cooling reservoir during May 1981.

during periods of normal plant operation. Movement into the main body of the discharge area did not occur until after the plant shut down (15 May) and surface temperatures decreased to 19.5° C. When the plant returned to full service (24 May), the walleyes left the discharge area and regrouped along the mixing area side of the T-dike. By early June, the walleyes began migrating to the intake area.

Shut down

Locations of the walleyes in June-August (Fig. 3) indicated that the fish preferred the intake area (76% of the locations). From June to mid-August, walleye activity was primarily concentrated in two discrete areas, termed activity centers (Fig. 5-7). The fish spent approximately 75 days (82% of the summer monitoring period) in these areas. Initially an activity center was established along the east arm of the T-dike where water temperatures averaged 25.0° C. During this period occasional excursions were made from the activity center to other parts of the intake and mixing areas. By late June, the walleyes abandoned the T-dike and established another activity center along the east shoreline and southeast corner of the reservoir. Although water temperatures reached 31.0° C, walleye continued to reside in this area. After spending up to 44 days in the eastern activity center, individuals left this area and moved back toward the T-dike activity center. By late August, activity centers were abandoned

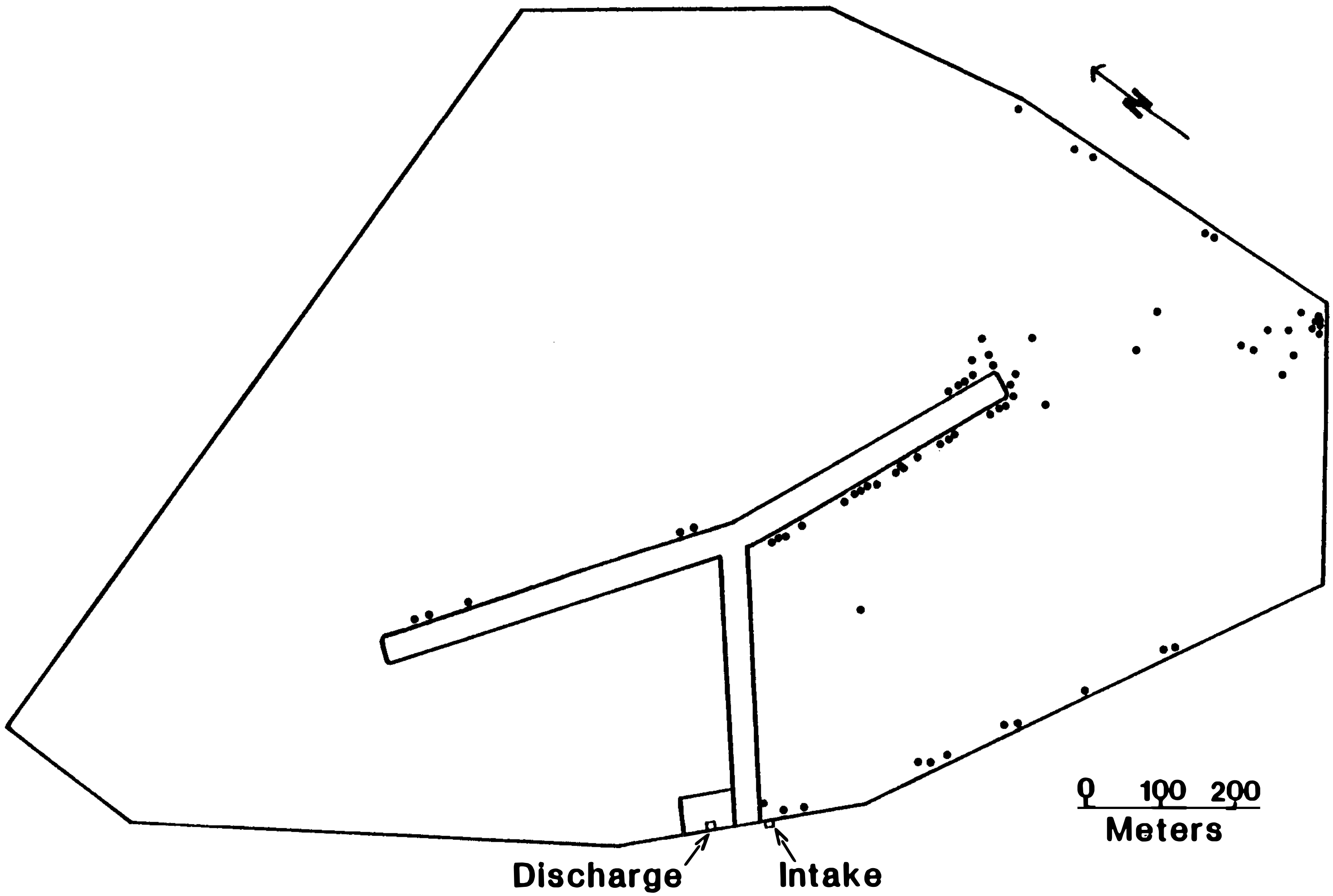

Fig. 5. Locations of adult walleyes (*Stizostedion vitreum vitreum*) monitored in Big Stone Power Plant cooling reservoir during June 1981.

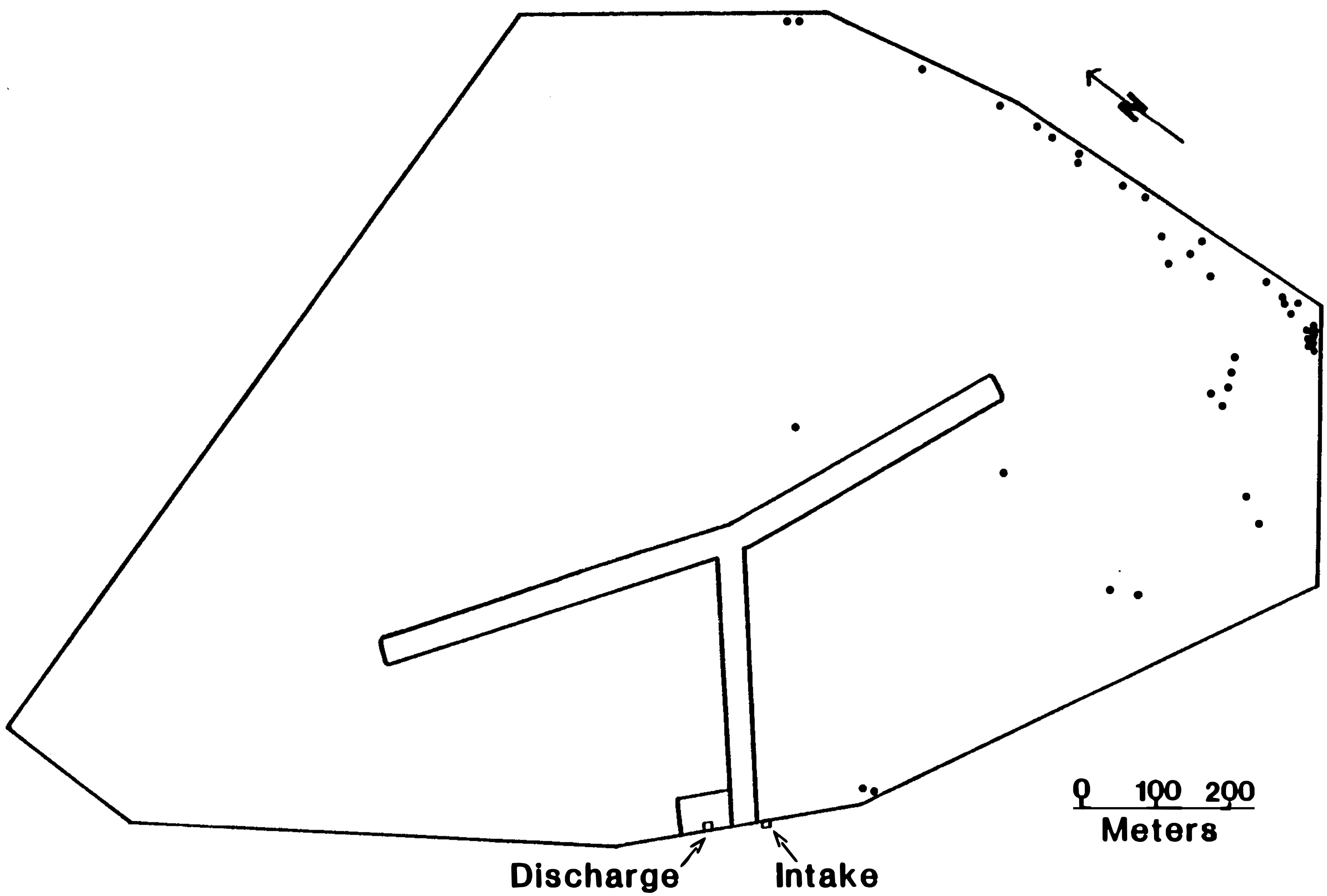

Fig. 6. Locations of adult walleyes (Stizostedion vitreum vitreum) monitored in Big Stone Power Plant cooling reservoir during July 1981.

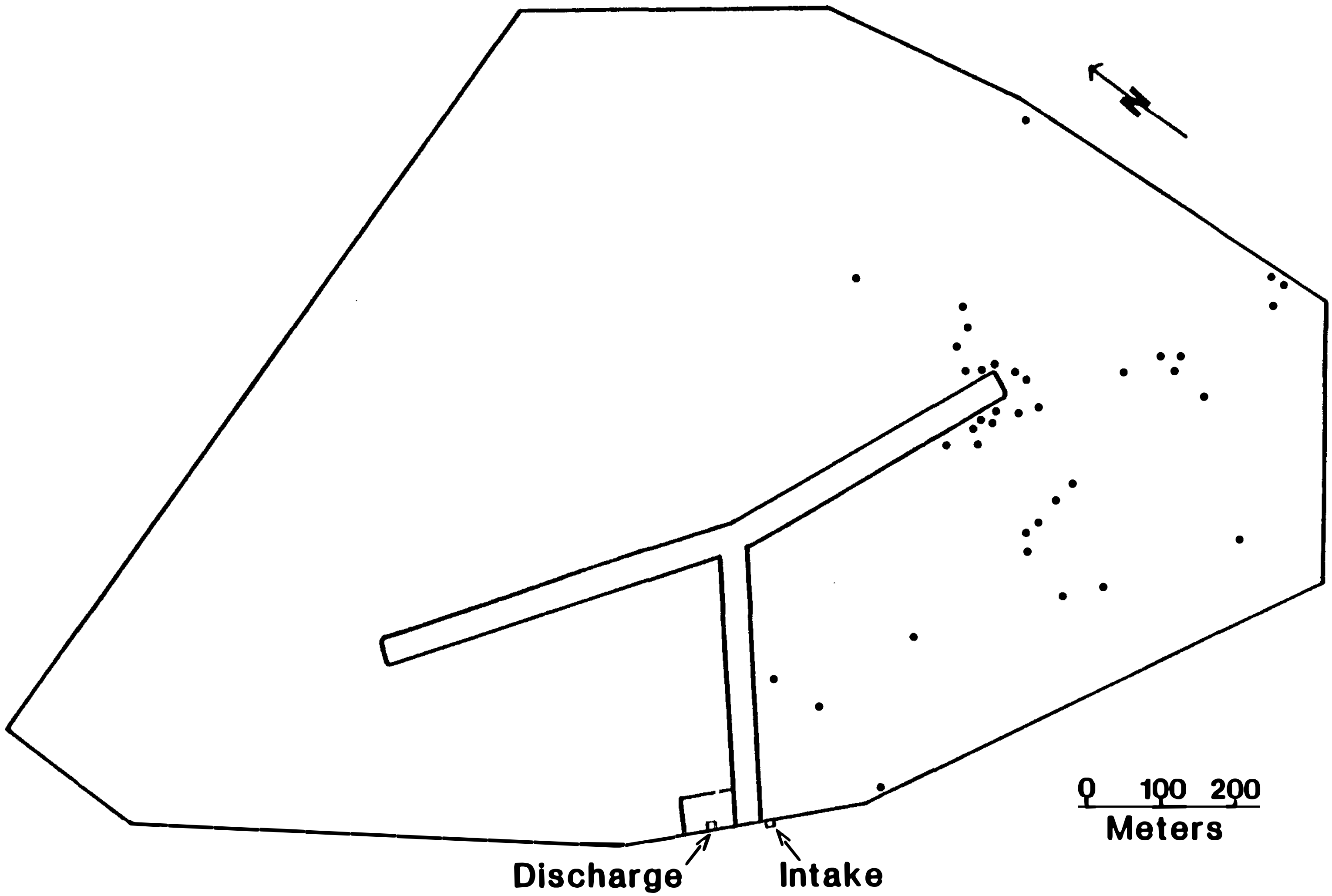

Fig. 7. Locations of adult walleyes (*Stizostedion vitreum vitreum*) monitored in Big Stone Power Plant cooling reservoir during August 1981.

and fish dispersed throughout the intake area. Locations of the fish in September-October showed a similar pattern with 80% of the locations within the intake area (Fig. 3). Individuals remained scattered throughout the intake area until early October when they again concentrated along the eastern shoreline of the reservoir (Fig. 8, 9). By mid-November the walleyes completed their migratory circuit and reestablished residency in the discharge area. In addition, individual walleyes returned to the same areas they had occupied the previous May (Fig. 9).

Shutdown Sept

Home Range

Three of the five walleyes monitored had a sufficient number of locations to estimate summer-fall home range parameters (Fig. 10-12). Maximum areas covered during this period were overlapping and confined to the south end of the reservoir; including most of the intake area and a portion of the mixing area. With the exception of walleye 87.4 (transmitter frequency), the summer-fall home ranges encompassed over 30% of the entire reservoir. The two female walleyes (81.2 and 84.6) resided in maximum areas averaging 45.3 ha, while the male (87.4) established a slightly smaller home range covering 36.7 ha (Table 2). By mid-October the fish began abandoning their summer-fall home range.

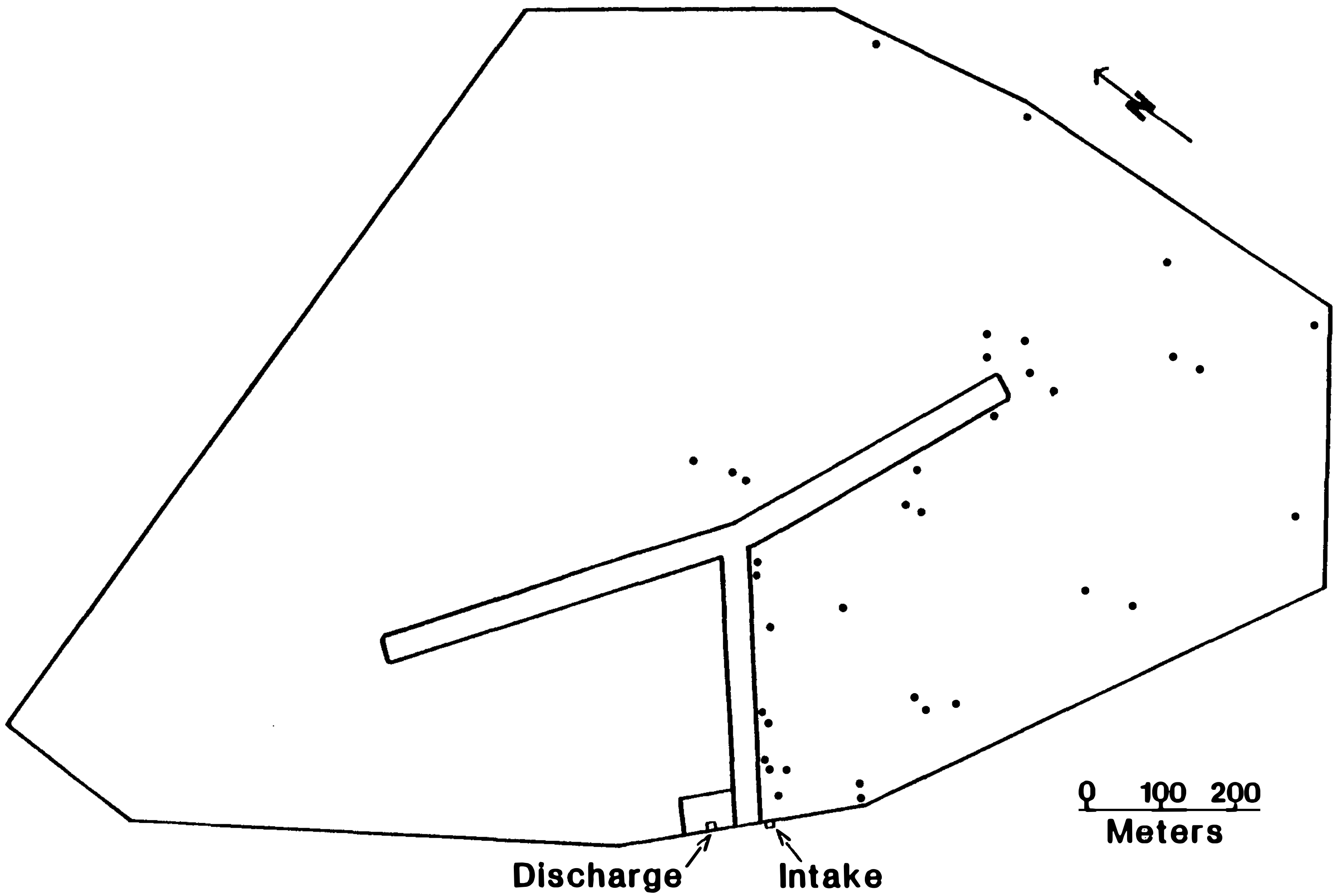

Fig. 8. Locations of adult walleyes (Stizostedion vitreum vitreum) monitored in Big Stone Power Plant cooling reservoir during September 1981.

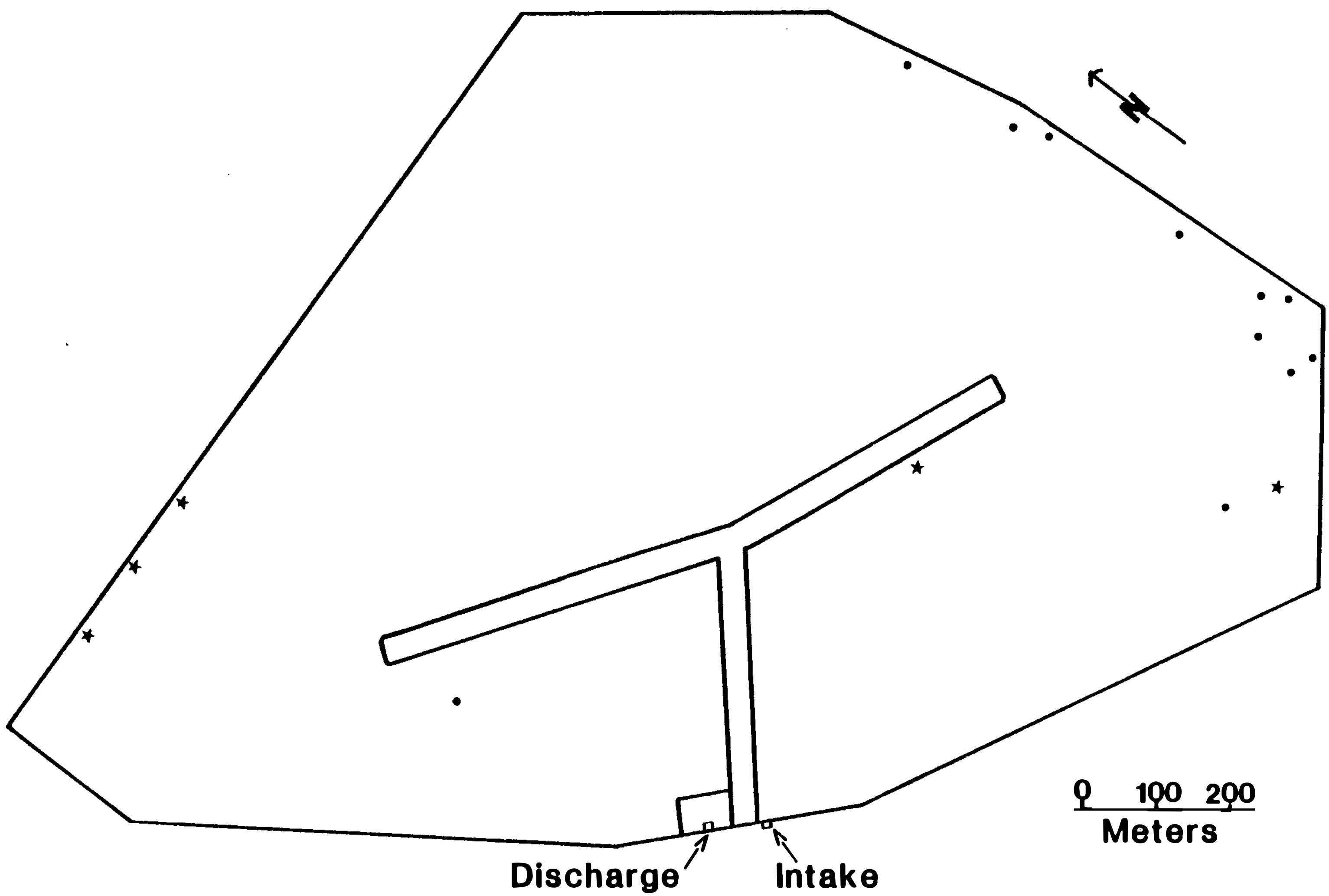

Fig. 9. Locations of adult walleyes (Stizostedion vitreum vitreum) monitored in Big Stone Power Plant cooling reservoir during October (•) and November (★).

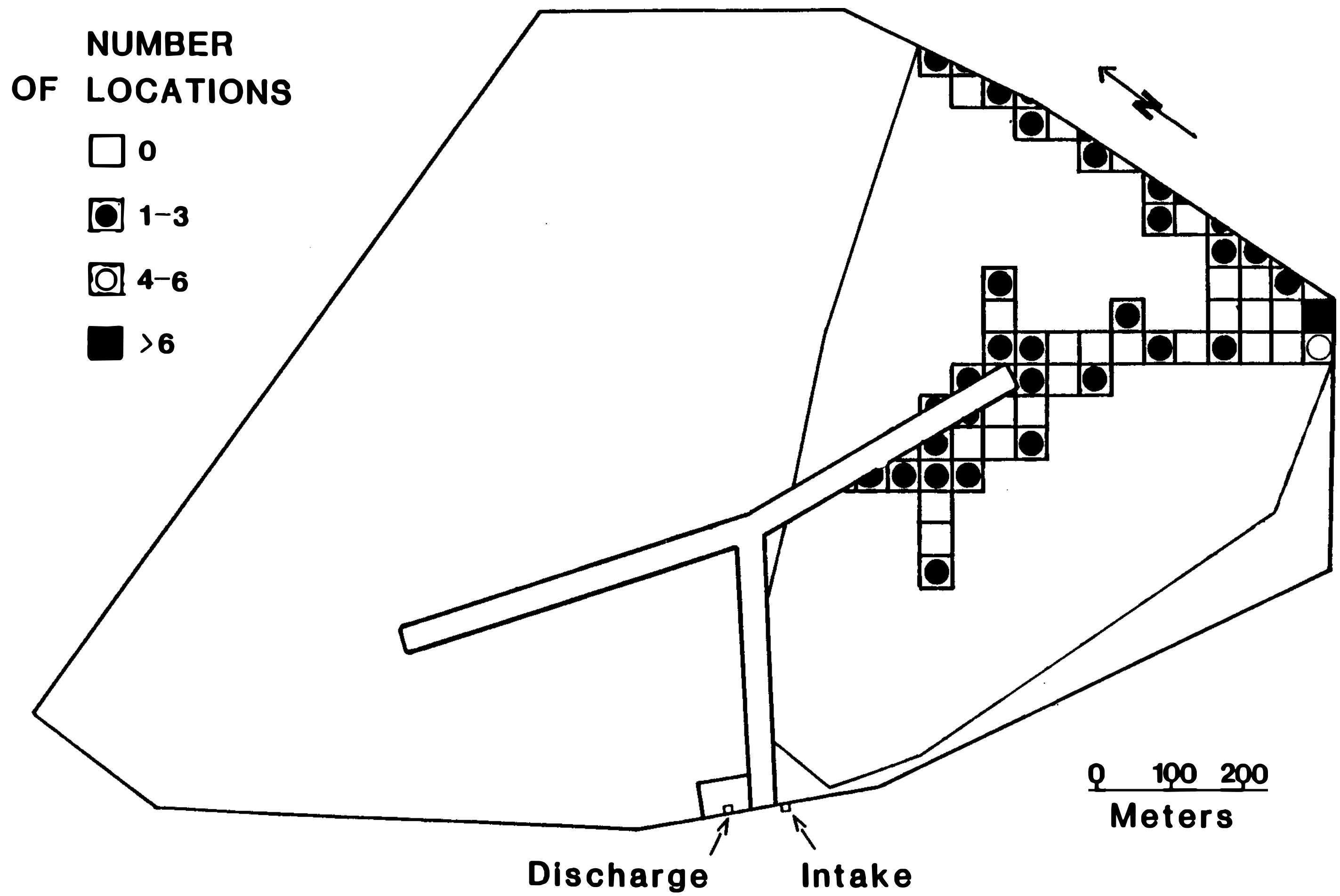

Fig. 10. Maximum (convex polygon) and utilized (grid-square) home range of walleye (Stizostedion vitreum vitreum) 81.2 in Big Stone Power Plant cooling reservoir, summer-fall 1981.

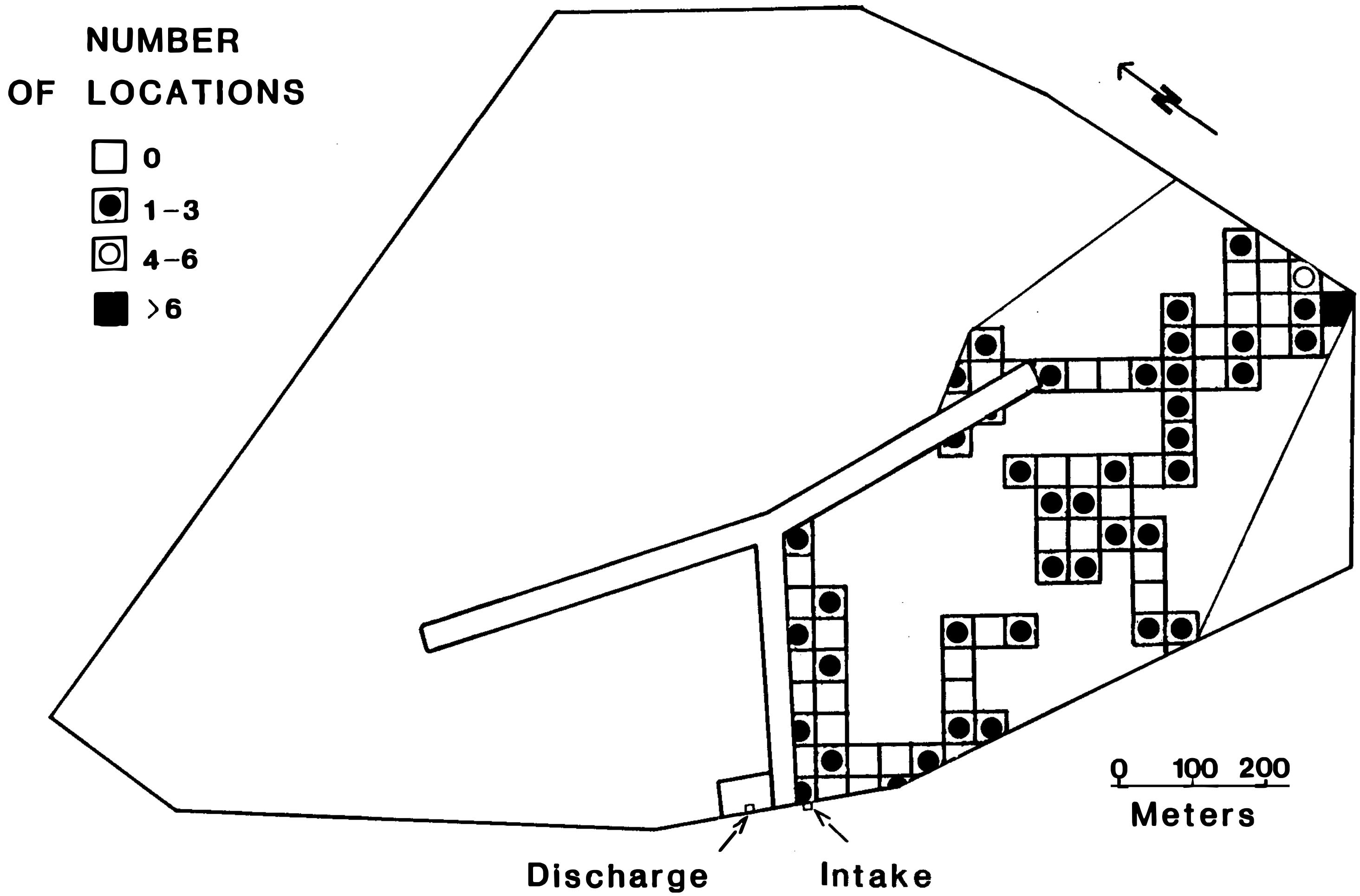

Fig. 11. Maximum (convex polygon) and utilized (grid-square) home range of walleye (Stizostedion vitreum vitreum) 87.4 in Big Stone Power Plant cooling reservoir, summer-fall 1981.

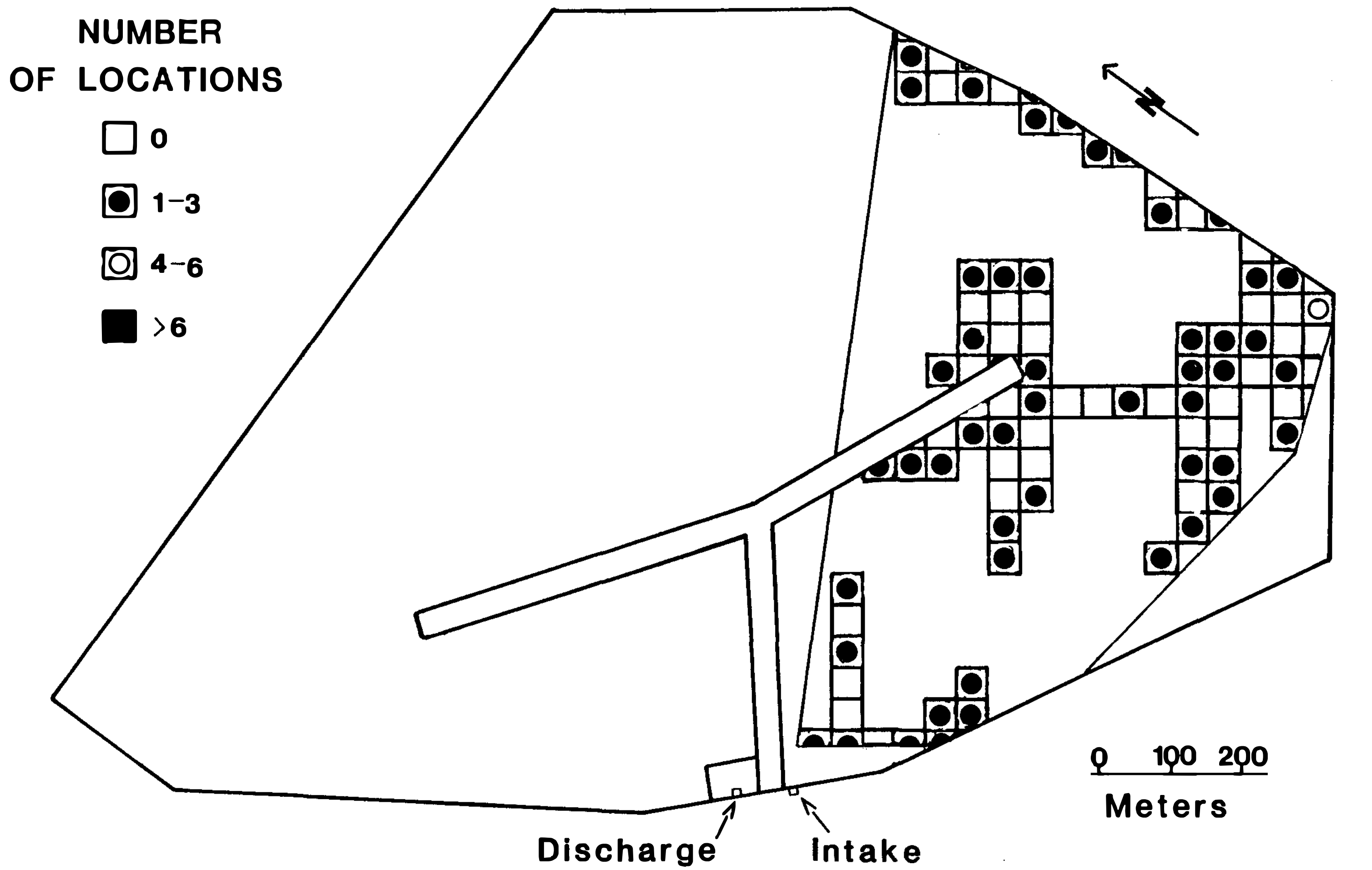

Fig. 12. Maximum (convex polygon) and utilized (grid-square) home range of walleye (*Stizostedion vitreum vitreum*) 84.6 in Big Stone Power Plant cooling reservoir, summer-fall 1981.

Table 2. Summary of home range and mobility estimates for five walleyes (*Stizostedion vitreum vitreum*) in Big Stone Power Plant cooling reservoir. NH=no home range.

	Fish No.				
	81.2	84.6	87.4	90.2	99.2
Home range					
Maximum area by convex polygon method (hectares)	44.8	45.9	36.7	NH	NH
Utilized area (hectares)	12.1	17.0	12.6	NH	NH
Mean distance between consecutive locations (m)	139.5	144.4	104.2	80.4	254.5
Range	72.7-250.1	57.8-226.4	66.1-151.4	51.5-109.2	-----

Locations encompassed by grid-squares (Fig. 10-12) represent that proportion of the maximum home range utilized by an individual. Overall, utilized areas represented less than 38% of the maximum home range of the individuals (Table 2) and contained 92% of the total locations. In addition, the actual areas of concentration, which were confined to the shoreline activity centers, accounted for 51% of the total locations.

Mobility

The mean daily distance moved by the walleyes varied considerably during the study (Fig. 13). A general trend of decreased movement occurred as the summer progressed, followed by increased movement in the fall. Mean daily movement was greatest during May (157.5 m) and June (186.8 m). As water temperatures increased during summer, the walleyes became more sedentary and movement rates decreased ($\bar{x}$=118.5 m/day). In the fall, movement was highest in September and November, averaging 129.3 m/day. The lowest mean daily movement rate occurred during October (65.5 m).

Excluding walleyes 90.2 and 99.2, there also were considerable differences in movement rates of individual fish (Table 2). Although mobility was greatest for the largest walleye, this individual showed a steady decline in mean daily movement rate throughout the study. In

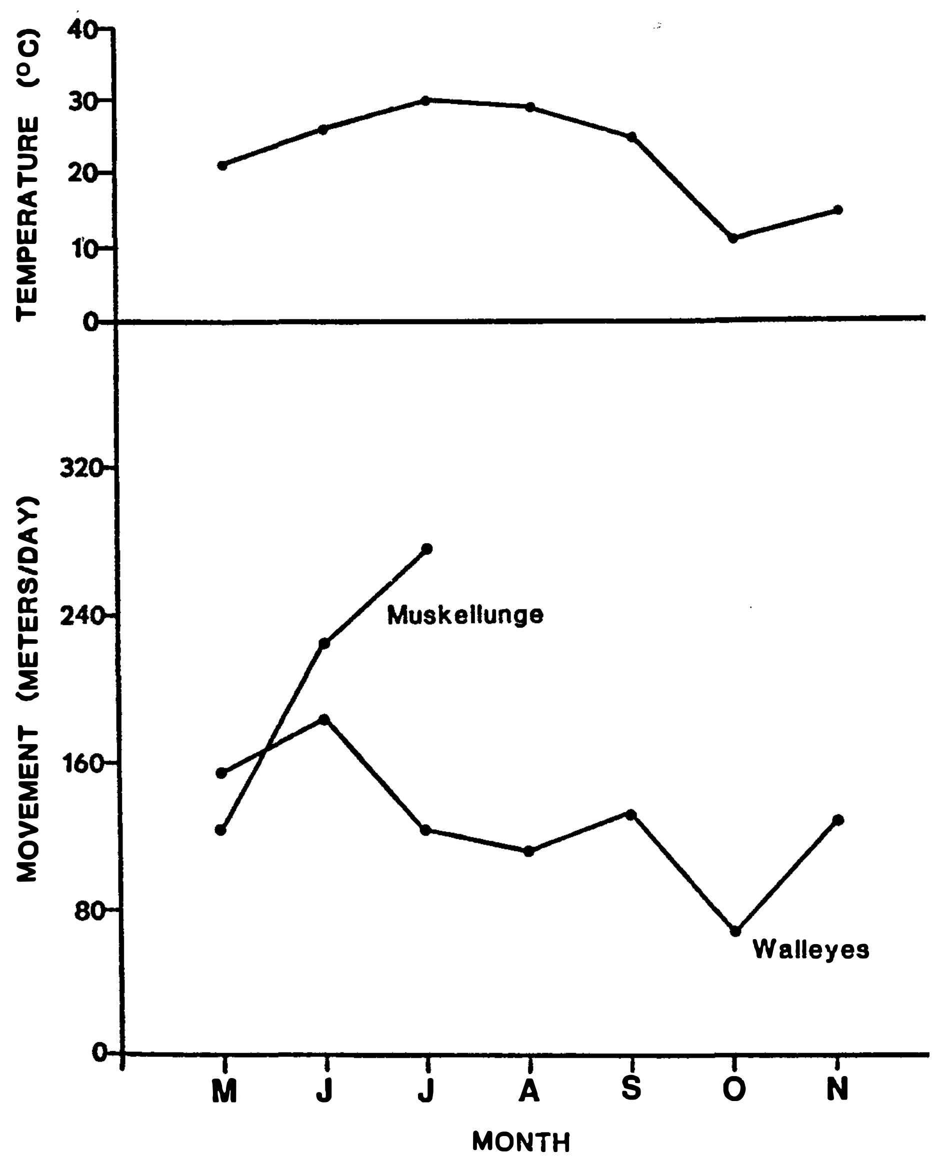

Fig. 13. Mean distance between consecutive locations for walleyes (*Stizostedion vitreum vitreum*) combined and one muskellunge (*Esox masquinongy*) in relation to the mean monthly water temperature, Big Stone Power Plant cooling reservoir, May-November 1981.

contrast, the other individuals exhibited a fluctuating movement rate similar to the overall trend illustrated in Fig. 13. There was no apparent reason for this difference in individual movement trends.

Due to the limited time walleyes 90.2 and 99.2 were tracked, estimated movement rates are biased (Table 2). However, these values further exemplify the temporal variation in mobility exhibited by walleye during the study.

Although areas of intensive use suggested localized movement, mobility expressed as the distances between locations and geometric centers of home range indicated that walleyes were wide ranging. Of the 222 locations, 8% were within 100 m, 54% were within 400 m, and 93% were within 500 m of the geometric centers (Fig. 14). The mean distance from the geometric centers of home range was 305.2 m.

Habitat Selection

The cooling reservoir was divided into two habitat classifications: shoreline (sloping rip-rap areas) and open water area (Table 3). From May to July, adult walleyes primarily occupied the shoreline areas. They ranged from 6.7-217.8 m offshore ($\bar{x}$=28.9 m) with 74% of the locations within 25 m of shore. During late summer and early fall this pattern was reversed with the majority of the observations located in open water areas. Mean

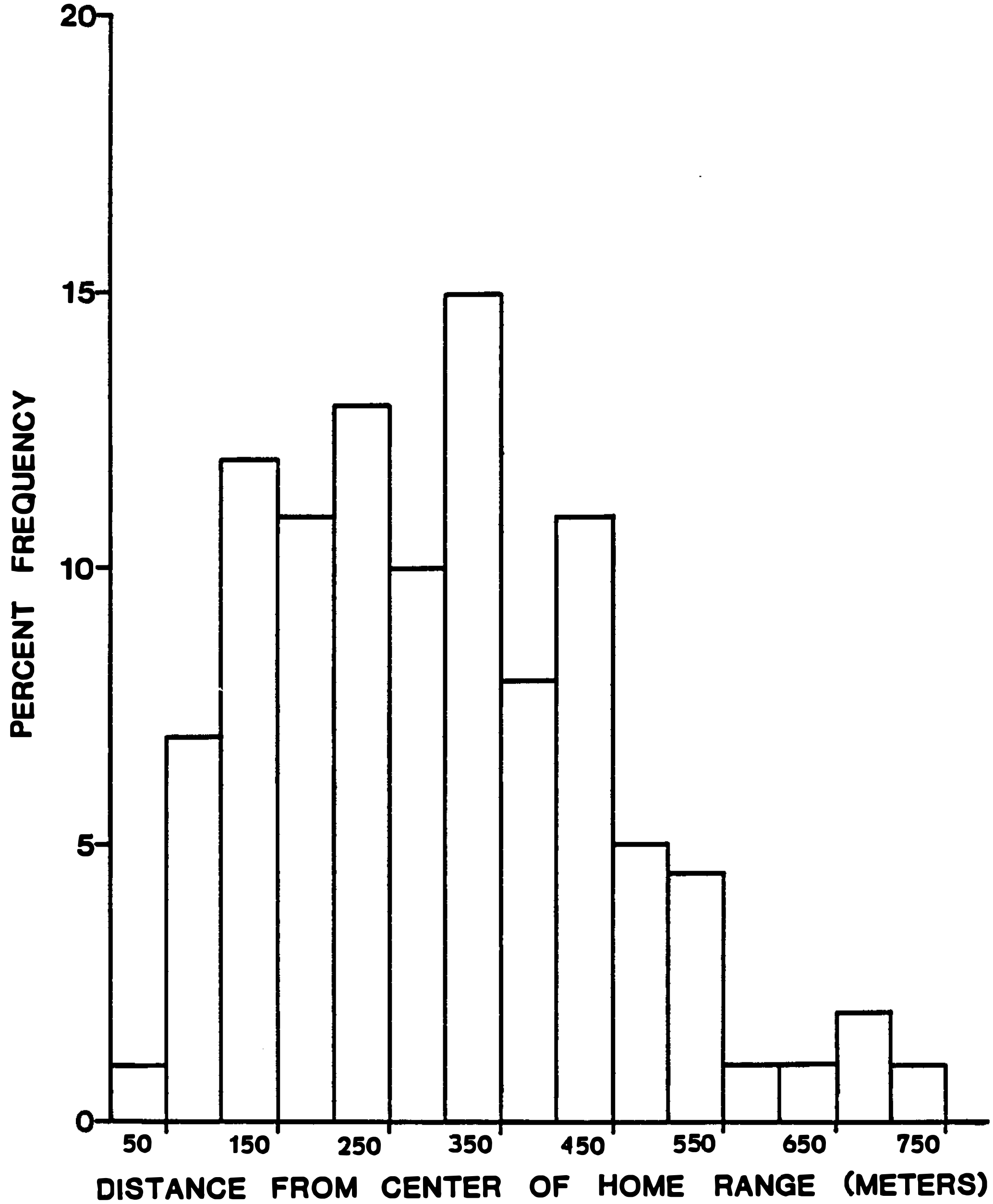

Fig. 14. Distribution of locations from the centers of home ranges of three adult walleyes (*Stizostedion vitreum vitreum*) in Big Stone Power Plant cooling reservoir, summer-fall 1981.

Table 3. The frequency and percent utilization of available habitat and mean depth of water occupied by adult walleyes (*Stizostedion vitreum vitreum*) in Big Stone Power Plant cooling reservoir, May-November 1981.

	Month					
Characteristic	May	June	July	Aug	Sept	Oct-Nov
Habitat:						
Rip-Rap	10(53%)	74(64%)	51(75%)	7(18%)	6(14%)	7(44%)
Open Water	9(47%)	41(36%)	17(25%)	31(82%)	37(86%)	9(56%)
Distance from shore:						
0- 24.9m	13(68%)	83(72%)	53(75%)	11(29%)	11(26%)	10(62%)
25- 49.9m	5(26%)	9(8%)	6(9%)	6(16%)	9(21%)	1(6%)
50- 74.9m	1(5%)	3(3%)	1(2%)	3(8%)	3(7%)	2(13%)
75- 99.9m		1(1%)			4(9%)	1(6%)
100-124.9m		5(4%)		1(3%)	3(7%)	1(6%)
125-149.9m		3(3%)	1(2%)	8(21%)	1(2%)	
150-174.9m		3(3%)	4(6%)	6(16%)	6(14%)	1(6%)
175-199.9m		1(1%)	2(3%)	2(5%)	2(5%)	
200m +		7(6%)	1(2%)	1(3%)	4(9%)	
Depth:						
Mean (m)	3.0	3.3	3.4	4.9	4.0	3.7
S. D.	1.15	1.22	1.42	1.35	1.61	.87
Range (m)	1.0-6.5	1.5-6.3	1.5-10.0	2.0-9.0	1.5-7.5	2.3-5.5

distance offshore during this period was 89.0 m. In addition, this was the only time less than 30% of the locations were within 25 m of shore. By late fall, utilization of both shoreline and open water areas were nearly equal. The walleyes were located an average of 35.8 m offshore with locations within 25 m of shore occurring 62% of the time.

Depths in which walleyes were located ranged from 1.0-10.0 m with a mean depth of 3.7 m (Table 3). The area of depths available in the reservoir were: 0-3.0 m (53%), 3.1-7.0 m (36%), and 7.1-10.0 m (11%). Fifty-five percent of all observations were located in the 0-3.0 m depth range; the most frequent depth in which walleyes were located was 3.0 m. Walleye frequencies of occurrence with respect to available depth categories were highly significant (x^2=32.13). There were significantly fewer ($P < .01$) observed locations than expected in water depths greater than 7.0 m (x^2=25.29).

Seasonal changes in depth selection corresponded to changing water temperatures and plant operations (Fig. 15). In May, walleyes occupied relatively shallow water ($\bar{x}$=3.0 m). As water temperatures increased during the summer, walleyes moved to progressively deeper areas (Fig. 15). During August, 82% of the locations were recorded in 4.0-6.5 m depths. In the fall, a less restricted depth range was evident during September,

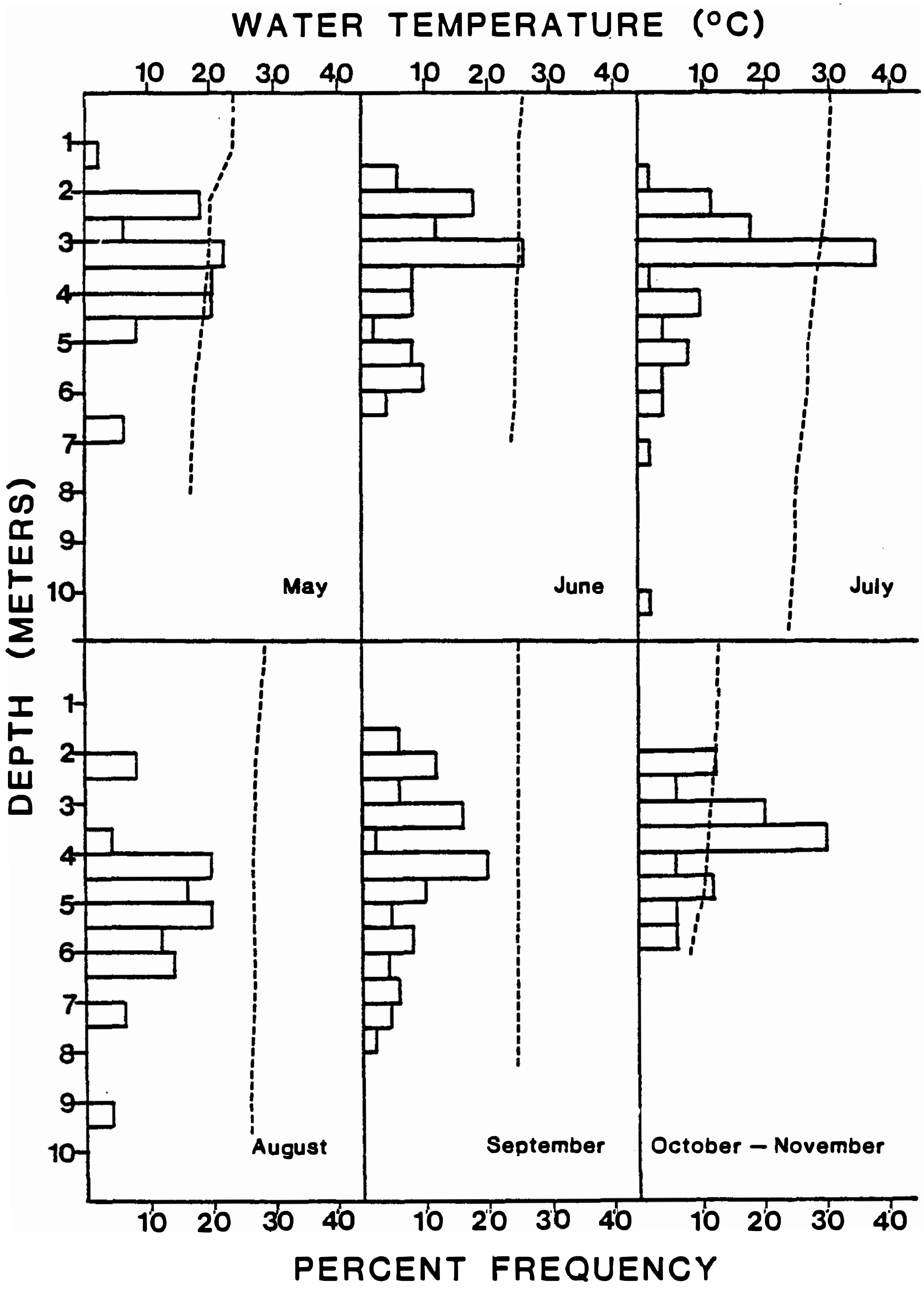

Fig. 15. Frequency distribution of water depths in which adult walleyes (Stizostedion vitreum vitreum) were located and mean monthly temperature profiles, Big Stone Power Plant cooling reservoir, May-November, 1981.

whereas, depths occupied by the walleyes during October-November were more confined (79% within 2.0-3.9 m depths) (Fig. 15). This variation in fall depth selection coincided with two distinct plant functions: plant shut-down during September and the introduction of make-up water during October.

Shut Down

Body Temperatures

The frequency distribution of the 278 recorded body temperatures for the four walleyes (data from one walleye was excluded due to a malfunctioning transmitter) was negatively skewed (Fig. 16). The range in body temperatures over the entire study period was 7.0-30.0° C with a modal temperature of 25.0° C ($\bar{x}$=25.2° C). Fifty-two percent of the recorded body temperatures ranged from 24.0-26.0° C and 80% were between 24.0-28.0° C. The majority of the observations were recorded during periods of normal plant operation when the greatest range of temperatures were available. However, of those body temperatures less than 20.0° C, 86% occurred during periods of relatively homothermic temperature conditions.

In general, walleyes encountered progressively warmer water during the summer months followed by an abrupt decrease in water temperatures in the fall (Fig. 17). Mean monthly body temperatures ranged from 10.9° C (mode 11.0° C) in October to 28.1° C (mode 28.0° C) in

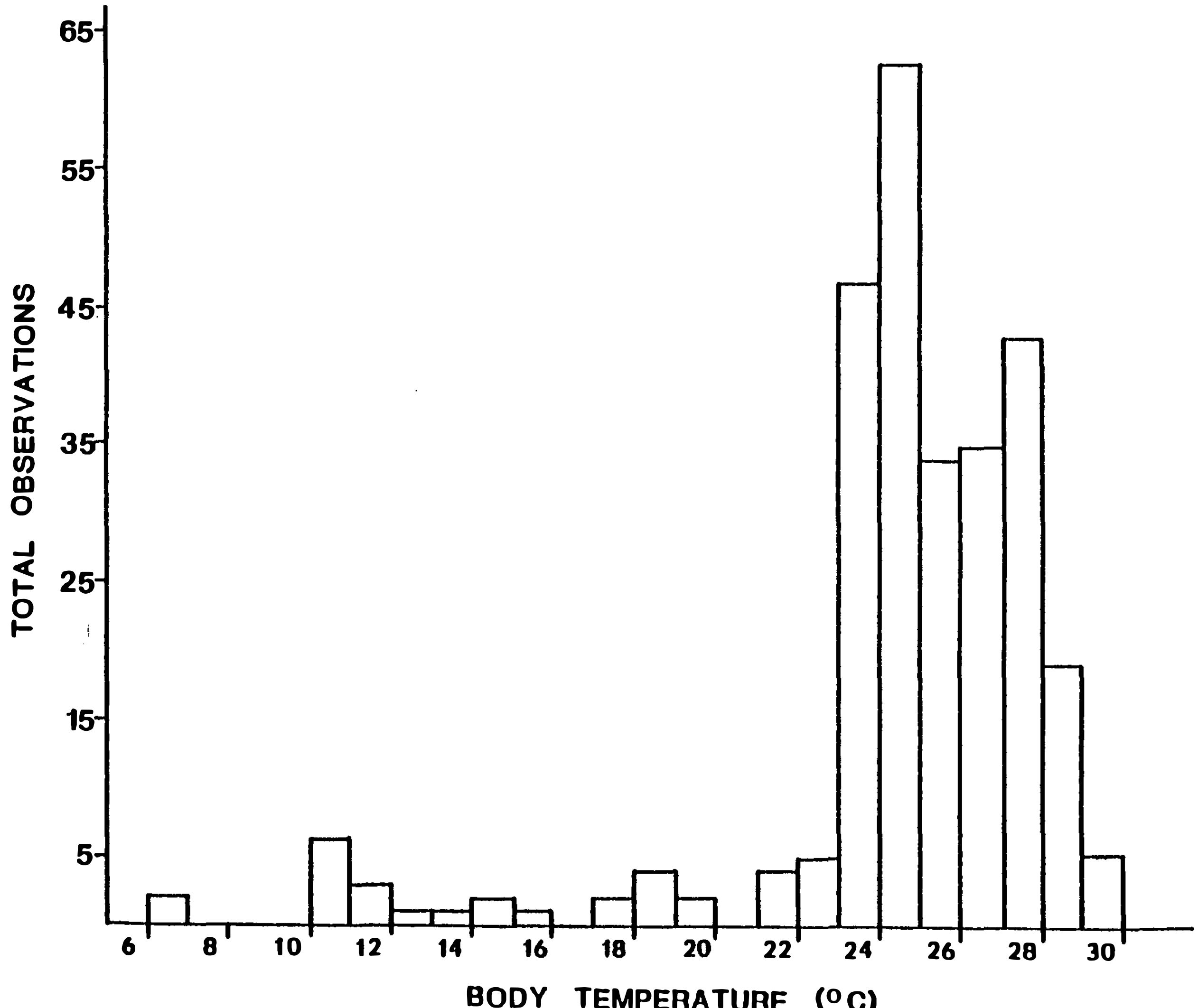

Fig. 16. Frequency distribution of body temperatures of adult walleyes (Stizostedion vitreum vitreum) in Big Stone Power Plant cooling reservoir, May-November, 1981.

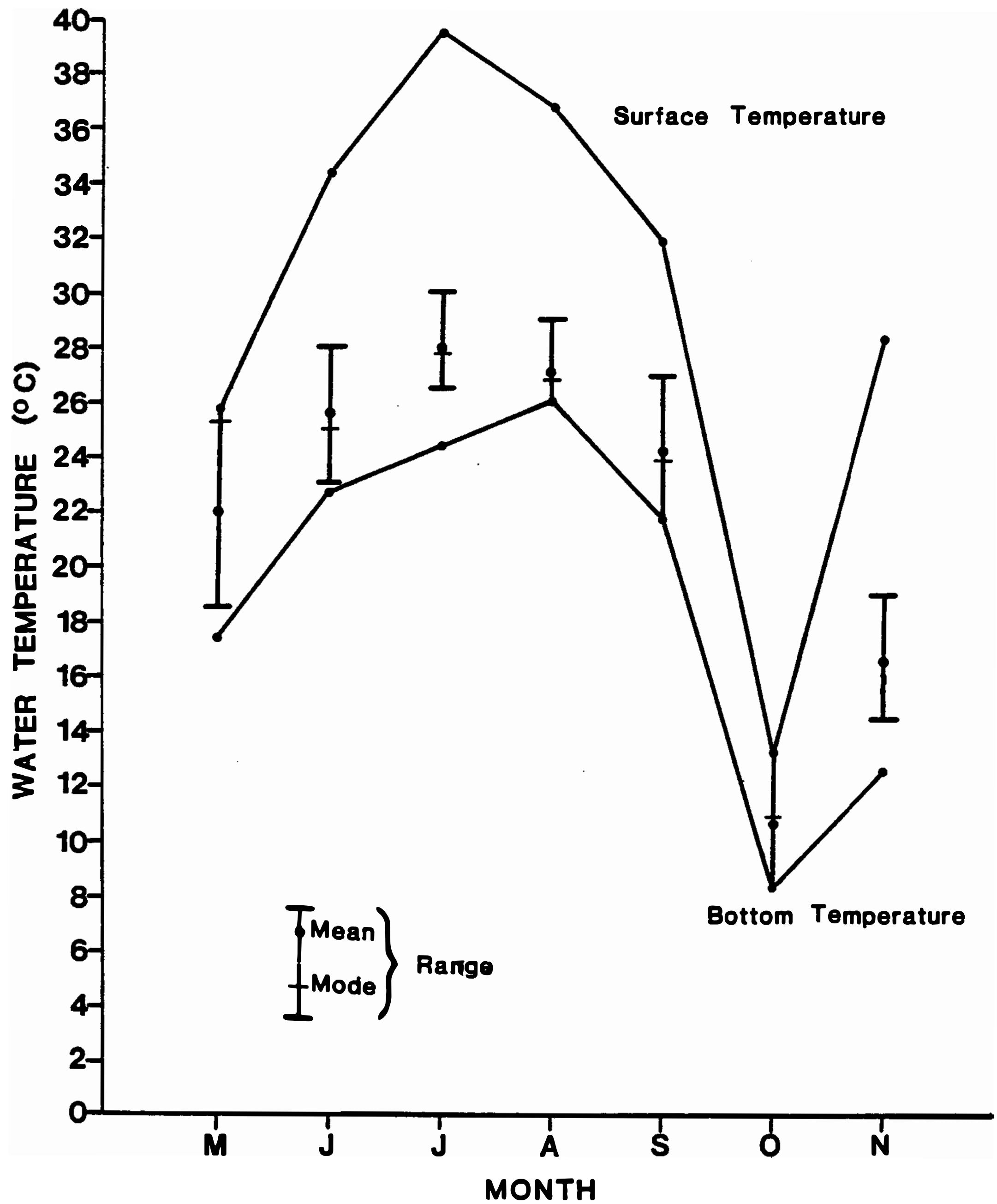

Fig. 17. Mean, mode, and range of body temperatures of adult walleyes (*Stizostedion vitreum vitreum*) in relation to mean monthly surface and bottom temperatures, Big Stone Power Plant cooling reservoir, May-November, 1981.

July. Mean body temperatures increased 5.7° C from May to July, increasing by an average of 2.9° C a month. During this same time period, mean surface temperatures increased 13.6° C with an average monthly increase of 6.8° C. The highest body temperature recorded (30.0° C) occurred during July when water temperatures were highest. Body temperatures started to decline in August with the greatest decline occurring in October when body temperature decreased 13.8° C. Monthly differences between mean body temperature and mean surface temperature varied substantially (1.9-12.3° C) during the study period.

Frequently, walleyes had body temperatures warmer than the coolest temperature at the point of location, indicating fish were inhabiting the warmer upper strata of the water column (Fig. 18 A and F). In contrast, particularly during the warmer periods (Fig. 18 C and D), walleyes had body temperatures cooler than the water in which they were found suggesting the fish were making short excursions into the cooler, deep water areas (greater than 5.0 m). However, with low dissolved oxygen values during these periods, walleyes were never observed permanently residing in depths greater than 5.0 m. The majority of body temperatures corresponded most closely to the minimum temperature at point of location (Fig. 18 B, E, and F).

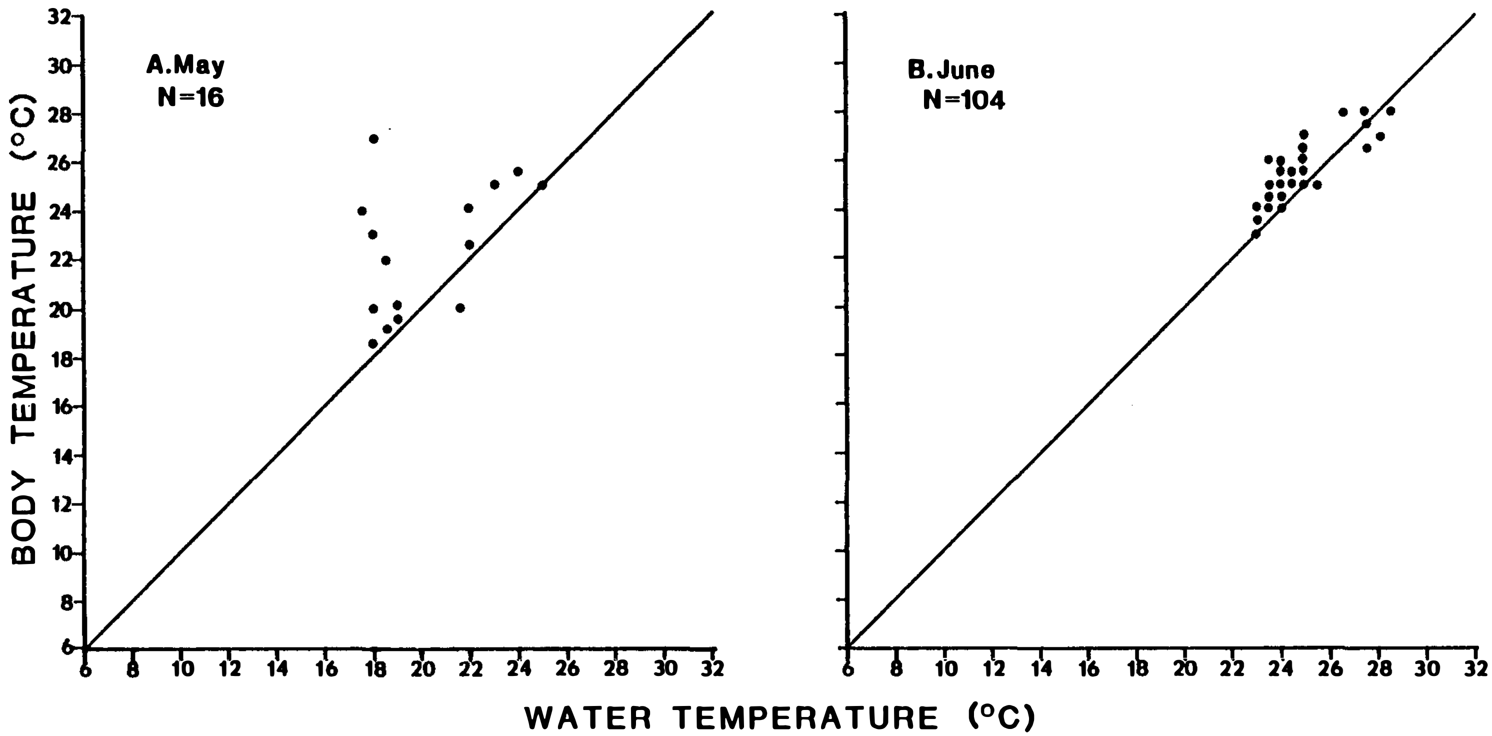

Fig. 18. Body temperatures of adult walleyes (*Stizostedion vitreum vitreum*) in relation to the minimum water temperatures at point of location, Big Stone Power Plant cooling reservoir, May-November, 1981.

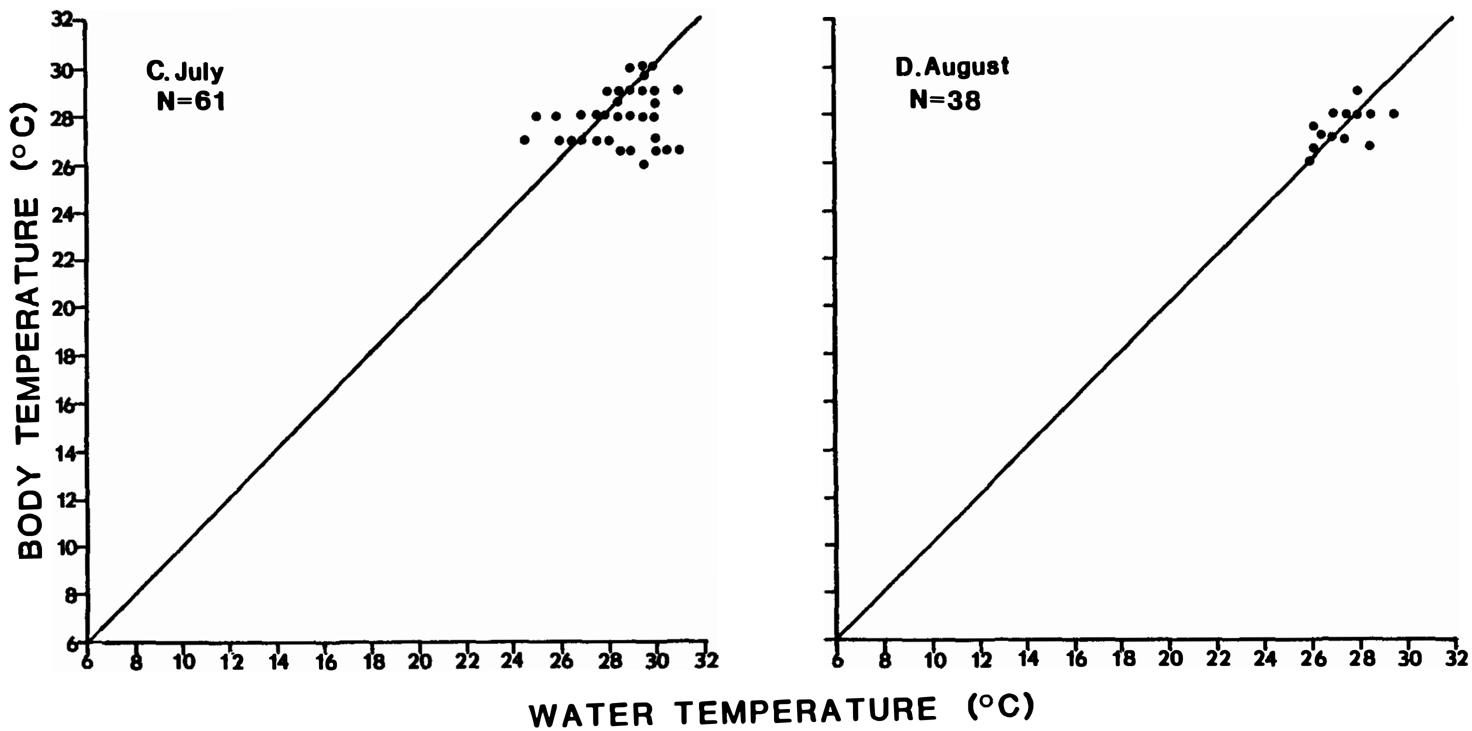

Fig. 18. continued.

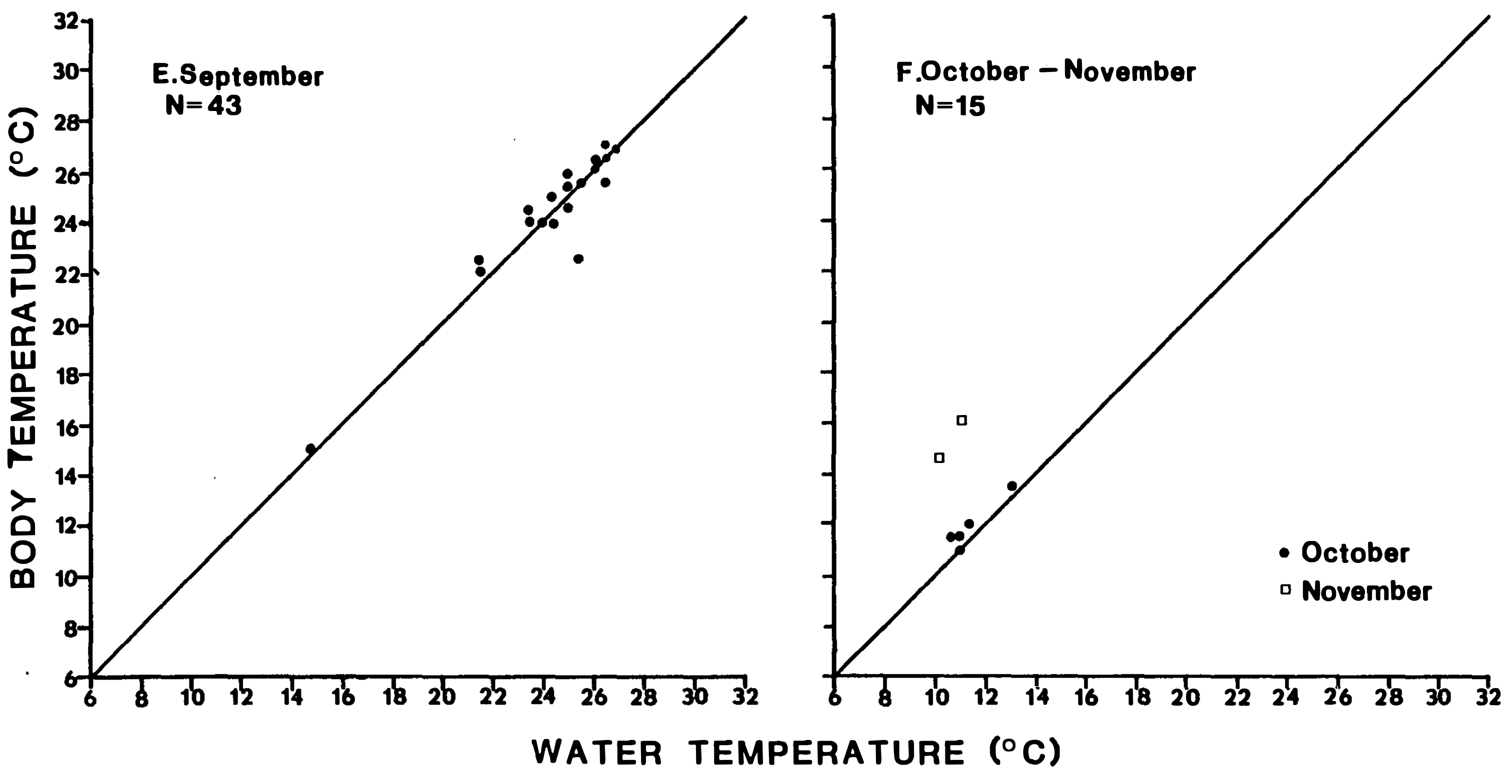

Fig. 18. continued.

Distribution and Movement of Muskellunge

The muskellunge exhibited extensive movement throughout the monitoring period. During May, the fish primarily inhabited the mixing area, whereas, during June and July it utilized both the intake (71% of the time) and mixing (29% of the time) areas. From June-July the muskellunge utilized a 10.4 ha area (Fig. 19). This area accounted for 86% of the total locations recorded during the 34 day period.

As water temperatures increased daily distance moved increased (Fig. 13). Movement rates ranged from 125.3 m/day in May to 278.1 m/day in July. The average daily distance moved for the entire period was 209.0 m/day.

The muskellunge consistently selected deeper, offshore areas of the reservoir (Table 4). Distance from shore ranged between 13.3-174.2 m and averaged 81.2 m. Ninety-five percent of all recorded locations were at a distance greater than 25.0 m from shore. Water depths in which the muskellunge were located ranged from 2.5-10.0 m. Of the 42 locations, 71% were observed in 4.0-7.5 m depths with the most frequent locations (26%) occurring in 4.5 m depths. Only during June were locations recorded in depths greater than 8.0 m.

Body Temperatures

Mean body temperatures of the muskellunge ranged

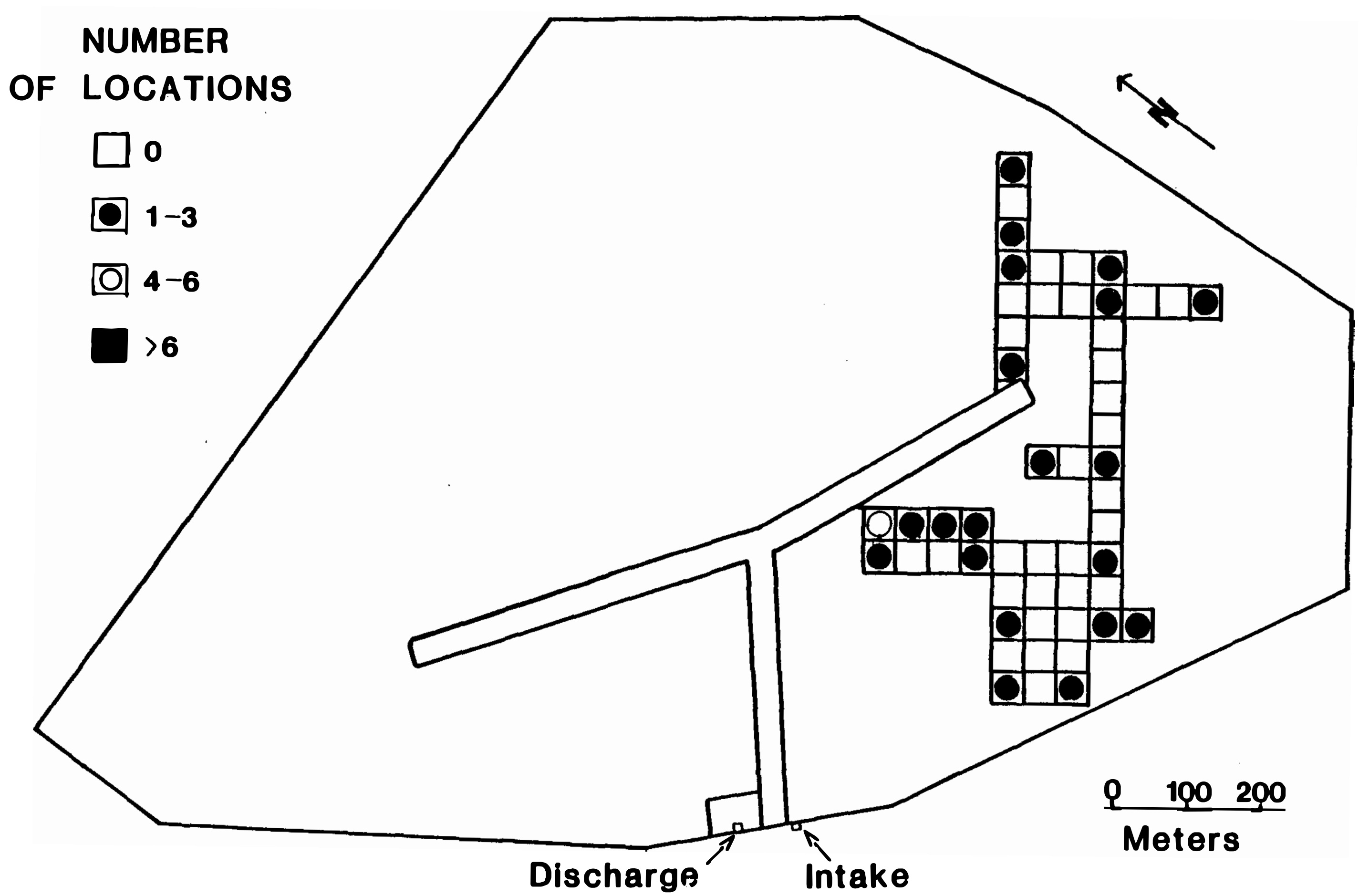

Fig. 19. Utilized home range of one adult muskellunge (*Esox masquinongy*) in Big Stone Power Plant cooling reservoir, June-July, 1981.

Table 4. Summary of home range, mobility, habitat characteristics and body temperature for one muskellunge (*Esox masquinongy*) monitored in Big Stone Power Plant cooling reservoir, May-July 1981.

	Month		
	May	June	July
Home range utilized area	June-July 10.4 hectares		
Mean distance between consecutive locations (m)	125.3	223.6	278.1
Mean depth of water occupied by fish (m)	3.6	5.2	6.3
S. D.	1.38	1.63	.25
Range	2.8-6.0	2.5-10.0	6.0-6.5
Mean distance from the shore (m)	73.7	89.5	80.4
Range	13.3-147.4	20.1-174.2	26.8-134.0
Body temperature (° C)			
Mean	22.8	25.0	27.0
Mode	24.0	25.0	27.0
S. D.	1.64	.38	-
Range	20.0-24.0	24.0-26.0	-

from 21.8° C in May to 27.0° C in July (Table 4). Modal body temperatures were similar, ranging from 24.0° C in May to 27.0° C in July. The most frequently recorded body temperature was 25.0° C (72% of the observations). Grand mean during the monitoring period was 24.6° C. In May, when water temperatures were cooler, the muskellunge showed considerable thermal variation, however, during summer, the fish occupied a progressively narrower temperature range (Table 4). Mean monthly body temperatures increased 5.2° C from May-July with the greatest increase (3.2° C) occurring between May-June.

Generally, the muskellunge had a body temperature similar to that of the lowest water temperature at the point of location (Fig. 20). However, on several occasions during May and July body temperatures corresponded more closely to temperatures of the warmer upper regions of the water column (Fig. 20).

The muskellunge was last located on 4 July 1981. Water temperatures at point of location ranged from 26.0-31.0° C; observed body temperature was 27.0° C. On 9 July 1981 the muskellunge was found dead along with 11 other muskellunge ranging from 755-935 mm in length (TL) and 3.3-5.6 kg in weight (Table 5). Intake and mixing area mean water temperatures ranged from 29.5° C (bottom) to 30.2° C (surface) and 27.9° C (bottom) to 33.1° C (surface), respectively. From 10 July to 24 July 1981 an additional

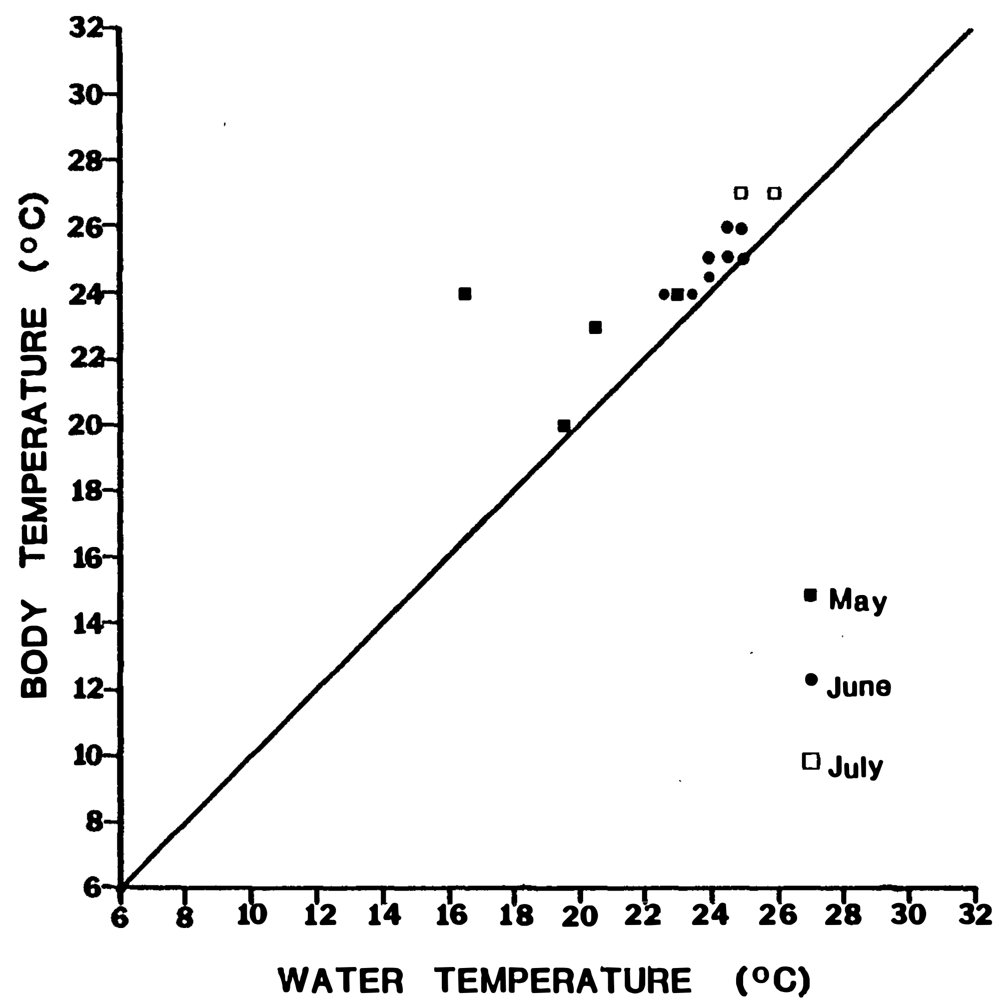

Fig. 20. Body temperatures of one adult muskellunge (*Esox masquinongy*) in relation to the minimum water temperature at point of location, Big Stone Power Plant cooling reservoir, May-July, 1981.

Table 5. Length and weight of muskellunge (Esox masquinongy) found dead during the period of 9 July to 24 July 1981, Big Stone Power Plant cooling reservoir.

Date	Number of fish	Mean total length (mm)	Range	Mean weight (kg)	Range
9 July	12	761	755-935	4.3	3.3-5.6
10 July	9	806	690-900	4.1	3.4-5.4
11 July	4	805	764-875	3.7	3.1-4.7
12 July	11	824	776-864	4.0	3.3-4.7
13 July	3	849	790-907	4.5	3.6-5.3
15 July	2	-	-	-	-
16 July	2	836	772-900	4.1	3.3-4.9
17 July	3	768	710-865	3.2	2.5-4.4
18 July	3	819	799-835	3.8	3.3-4.0
20 July	3	782	759-817	3.3	3.0-3.7
22 July	6	832	813-860	4.2	4.1-4.3
24 July	1	-	-	-	-

47 muskellunge ranging from 710-907 mm in length (TL) and 2.5-5.4 kg in weight were found dead (Table 5). Mean water temperatures of the intake and mixing area during this period ranged from 28.8° C (bottom) to 30.2° C (surface) and 27.2° C (bottom) to 31.7° C (surface), respectively. Although the die-off occurred over a period of 16 days, 36 (61%) of the dead muskellunge were found during the first 4 days.

Physicochemical Parameters

Water temperatures in the cooling reservoir ranged from 6.8-42.5° C during the study period (Table 6). In May mean water temperature was 21.2° C in the discharge area and 19.8° C in the intake area. From 15 May to 24 May the plant was shut down for maintenance, resulting in temperatures dropping to an average of 19.0° C throughout the reservoir. During June, mean water temperatures averaged 27.8° C in the discharge area and 24.9° C in the intake area. The highest water temperatures recorded occurred in July, averaging 32.6° C in the discharge area and 29.3° C in the intake area. The maximum mean temperature recorded in the discharge and intake area was 33.4 and 30.6° C (17 July), respectively. Water temperature was lowest at station 4, averaging 27.9° C. During August mean water temperatures declined slightly, averaging 31.8° C in the discharge area and 27.9° C in the intake area. In

Table 6. Maximum, minimum, and mean monthly temperatures ($^{\circ}$ C) at 1.0 meter depth intervals in Big Stone Power Plant cooling reservoir, May-November 1981.

Month	Area		Depth (m)										
			Surface	1	2	3	4	5	6	7	8	9	10
May													
	Intake	Min	19.0	18.5	18.5	18.5	18.0	18.0					
		Max	24.0	23.5	23.0	23.0	22.0	18.5					
		Mean	20.5	20.3	20.2	19.9	19.3	18.2					
	Mixing	Min	19.5	19.5	19.5	18.5	18.0	17.5	17.5	17.5			
		Max	30.0	29.0	24.0	21.5	19.0	18.5	17.5	17.5			
		Mean	23.8	23.7	20.8	19.3	18.2	17.8	17.5	17.5			
	Discharge	Min	19.5	19.0	18.5	18.0	18.0	18.0					
		Max	29.0	29.0	22.0	19.5	18.5	18.0					
		Mean	24.4	23.8	19.8	18.6	18.1	18.0					
June													
	Intake	Min	22.5	23.0	23.0	23.0	23.0	21.5	21.0	22.0			
		Max	28.5	28.5	28.0	28.0	28.0	27.5	25.0	25.0			
		Mean	25.1	25.2	25.1	25.0	24.8	24.4	23.8	23.8			
	Mixing	Min	23.5	23.5	23.0	23.0	22.0	20.5	20.0	19.5	19.0	18.0	
		Max	35.0	30.5	30.5	28.5	27.0	25.3	25.0	25.0	25.0	24.5	
		Mean	27.1	26.0	25.5	25.1	24.5	23.5	23.4	23.9	22.8	22.8	
	Discharge	Min	25.0	24.0	23.0	22.5	22.0	22.0					
		Max	39.0	38.0	30.0	25.3	25.0	24.8					
		Mean	32.7	30.9	25.0	24.0	23.8	23.2					

Table 6. continued.

			Depth (m)										
Month	Area		Surface	1	2	3	4	5	6	7	8	9	10
July													
	Intake	Min	27.0	27.0	27.0	27.0	26.8	25.8	25.5				
		Max	32.0	31.8	31.5	31.0	30.8	30.3	28.5				
		Mean	30.0	29.9	29.7	29.5	28.8	28.1	27.3				
	Mixing	Min	27.8	28.0	28.0	28.0	26.8	25.3	25.0	24.5	24.3	24.0	23.8
		Max	38.0	36.5	33.5	32.0	31.0	30.8	28.8	28.3	26.3	25.5	25.0
		Mean	31.9	31.5	30.3	29.6	28.9	28.2	27.4	26.3	25.5	24.8	24.4
	Discharge	Min	31.5	30.0	28.5	26.3	25.5	25.5					
		Max	42.5	41.0	34.0	31.5	30.0	29.3					
		Mean	37.7	35.3	30.4	29.4	28.1	28.2					
August													
	Intake	Min	26.0	26.0	26.0	26.0	26.0	26.0	26.3				
		Max	31.0	30.5	30.5	30.3	30.0	28.3	27.0				
		Mean	28.4	28.2	28.1	27.8	27.7	27.3	26.6				
	Mixing	Min	27.5	27.5	27.3	27.3	27.0	26.8	26.5	26.3	26.3	26.0	26.0
		Max	36.0	33.5	31.0	30.5	29.5	28.5	28.0	28.0	28.0	28.0	28.0
		Mean	30.1	29.4	28.5	28.1	27.9	27.6	27.3	27.1	26.9	26.9	26.6
	Discharge	Min	28.0	27.8	27.5	27.0	27.3						
		Max	40.0	38.0	33.0	30.3	29.5						
		Mean	35.2	33.4	29.4	28.3	28.3						

Table 6. continued.

Month	Area		Depth (m) Surface	1	2	3	4	5	6	7	8	9	10
September													
	Intake	Min	15.0	15.0	15.0	14.8	14.8	14.8					
		Max	28.5	28.5	28.0	28.5	28.0	27.0					
		Mean	24.7	24.6	24.5	24.3	24.1	23.4					
	Mixing	Min	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.5	14.5	14.3	
		Max	33.0	29.5	28.5	28.5	28.0	28.0	27.0	25.5	25.5	24.5	
		Mean	25.0	24.6	24.2	24.0	23.7	23.5	22.9	22.4	22.1	21.9	
	Discharge	Min	14.3	14.0	14.0	14.0	14.0						
		Max	40.0	38.0	37.0	28.0	26.8						
		Mean	29.8	28.4	25.2	23.5	22.8						
October													
	Intake	Min	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0			
		Max	12.5	12.5	12.0	12.0	12.0	12.0	11.3	11.0			
		Mean	10.4	10.3	10.3	10.2	10.1	9.2	9.0	8.7			
	Mixing	Min	6.8	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
		Max	15.0	14.0	13.0	13.0	13.0	13.0	12.8	12.8	12.8	12.5	11.0
		Mean	11.2	11.0	10.7	10.5	10.4	9.8	10.0	10.4	10.4	10.3	9.1
	Discharge	Min	7.0	7.0	7.0	7.0	7.0	7.0					
		Max	24.5	19.0	13.5	11.5	11.5	11.3					
		Mean	12.3	11.7	10.8	10.4	10.1	9.2					

Table 6. continued.

Month	Area		Depth (m)										
			Surface	1	2	3	4	5	6	7	8	9	10
November													
	Intake	Min	12.0	12.0	12.0	12.0	12.0	12.0	12.0				
		Max	14.0	14.0	14.0	14.0	13.8	13.5	13.5				
		Mean	12.9	12.9	12.9	12.9	12.9	12.8	12.8				
	Mixing	Min	14.0	14.0	13.5	13.5	13.0	13.0	13.0	12.5	12.5	12.5	12.5
		Max	19.5	19.5	19.0	19.0	19.0	19.0	14.0	13.8	13.5	13.0	12.5
		Mean	15.8	15.7	15.3	15.3	15.0	14.0	13.6	13.3	13.0	12.8	12.5
	Discharge	Min	20.0	14.5	13.0	12.5	12.0	12.0					
		Max	30.5	26.5	19.5	16.0	15.0	15.0					
		Mean	24.9	21.1	15.0	13.7	13.4	13.5					

September mean water temperature was 27.1° C in the discharge area and 24.4° C in the intake area. In September the plant was shut down for a period of approximately 5 weeks, resulting in a mean reservoir temperature of 14.7° C by the end of September. Water temperatures during most of October were homothermic between 7.0-12.0° C. During the first two weeks of November mean water temperature was 17.8° C in the discharge area and 12.9° C in the intake area. Throughout the study, mean water temperature of the intake and mixing area seldom differed by more than 1.0° C.

SHUT DOWN

Thermal stratification was evident in the discharge area during most of the study period. Heated water from the plant discharge formed a well defined surface plume. At times, surface temperatures in the discharge area exceeded temperatures 1.0 m in depth by 7.5° C. Beyond the discharge area thermal stratification was poorly defined. Surface temperatures rarely exceeded temperatures 1.0 m in depth by more than 2.0° C. Maximum water temperatures at the discharge typically exceeded the intake water temperature by 8.0-13.0° C.

Dissolved oxygen concentration in the surface waters ranged from 12.5 mg/l in May to 6.5 mg/l in August. Bottom dissolved oxygen values ranged from 12.7 mg/l in October to 0.0 mg/l in July. During July dissolved oxygen concentrations became critical in the deep water regions of the reservoir. On 13 July the dissolved oxygen concentrations were as follows: surface 7.3 mg/l, 5.0 m depth 2.5 mg/l, and 10.0 m depth 0.0 mg/l. By 27 August dissolved oxygen concentrations had increased to 1.4 mg/l at 10.0 m and 5.5 mg/l at 5.0 m depths. In October dissolved oxygen reached levels above 11.0 mg/l throughout the reservoir.

Secchi disk visibility averaged 1.1 m (range 0.6-2.0 m) throughout the study period (Table 7). Water clarity was greatest from May through July, declining during August and September, and followed by an increase in October and November. The discharge area was the most turbid region of the reservoir with visibility becoming progressively greater toward the intake area.

Table 7. Mean monthly Secchi disk visibility from the three areas of Big Stone Power Plant cooling reservoir, May-November 1981.

	Month						
	May	June	July	Aug	Sept	Oct	Nov
Intake area							
Mean (m)	1.5	1.2	1.2	0.9	0.8	1.0	1.1
Range	1.4-1.7	0.8-2.0	0.9-1.6	0.8-1.0	0.6-0.8	0.8-1.2	1.0-1.3
Mixing area							
Mean (m)	1.4	1.2	1.2	0.9	0.7	1.1	1.2
Range	1.2-1.7	0.9-1.7	0.9-1.5	0.9-1.0	0.6-0.8	0.9-1.1	0.9-1.4
Discharge area							
Mean (m)	1.3	1.2	1.1	0.9	0.7	0.9	0.9
Range	1.2-1.4	0.8-1.3	0.8-1.3	0.8-0.9	0.5-0.8	0.8-1.1	0.8-1.1

DISCUSSION

Adult walleyes monitored in Big Stone Power Plant cooling reservoir exhibited a distinct seasonal migration into and out of the discharge area. Previous studies of walleye behavior near a thermal discharge, although limited, have indicated similar results. Trembley (1960) reported that during winter, walleyes congregated in the discharge area of a power plant located on the Delaware River. Wrenn (1975) found that walleyes avoided heated zones when water temperatures reached above 30.0° C; however, from November to June they exhibited a distinct preference for the discharge area. In contrast, Ross and Winter (1981) found that walleyes were not attracted to the shallow discharge areas, but instead confined their winter activity to deeper, cooler areas of the discharge or left the area entirely. They did not know if this was the result of water temperatures, increased light intensity, or other factors. Several authors (Kelso 1976a; Minns et al. 1978) have suggested that turbulence rather than temperature affected fish movements around a power plant discharge.

Walleyes monitored during the present study concentrated along the periphery of the discharge area, apparently avoiding areas in the immediate vicinity of the outlet. When the plant shut down, but continued discharging without a heated load, walleyes moved into the main body of the discharge area. In contrast, when the plant began discharging heated water again, the walleyes immediately left the discharge area. In this study it appeared that temperature, which was considerably higher than in the other two studies, was the major factor influencing walleye behavior around the discharge. Coutant (1977) pointed out that abrupt temperature gradients of greater than 4.0-5.0° C may nearly always repel, even when temperatures are within the tolerance range of the fish.

Temperature selection, as determined by body temperature, indicated that walleyes were capable of tolerating a wide range of thermal conditions (body temperatures ranged from 7.0-30.0° C). During May, the walleyes were primarily found inhabiting the upper warm water strata of the reservoir. The only exception to this pattern occurred during periods of plant shut-down when temperatures were relatively homothermic. Mean body temperature during this month was 21.9° C (mode 25.0° C). As summer progressed, the walleyes gradually increased their thermal experience. Mean body temperatures ranged from 25.3° C (mode 25.0° C) in June to 28.1° C (mode 28.0° C) in July. The maximum body temperature recorded, which occurred during July, was 30.0° C. Trembley (1960) reported that maximum body temperature of walleyes caught by angling near a thermal discharge was 28.9° C; he also observed heat death at a body temperature of 30.6° C.

Wrenn (1975) reported that walleyes avoided discharge temperatures above 30.0° C. Although permanent summer occupancy of deeper, cooler (less oxygenated) areas of the cooling reservoir was not observed, it was apparent from body temperatures that walleyes made occasional excursions into these areas. Laboratory studies have indicated that walleye may be capable of tolerating dissolved oxygen concentrations as low as 2 mg/l (Hoff and Chittenden 1969). By late summer, the walleyes began to inhabit progressively lower water temperatures. Mean body temperatures ranged from 27.3° C (mode 27.0° C) in August to 16.6° C in November. The decline in temperatures during October was again in response to plant shutdown. Walleyes exhibited no adverse affects to the fluctuating temperature gradients.

In contrast, temperature preference in unaltered lakes and reservoirs was considerably lower. In Norris Reservoir, Tennessee, walleyes avoided temperatures above 24.0° C (Fitz and Holbrook 1978). Summer body temperatures of walleyes monitored in West Lake Okoboji, Iowa ranged from 20.0-25.0° C, with a mean of 21.9° C (Pitlo 1978). Body temperatures of walleyes in the cooling reservoir were also in excess of the physiological optimum of 22.0° C (Hokanson 1977). The reason for this discrepancy in temperature preference may involve individual responses to variation in factors such as light intensity, dissolved oxygen, and food availability. It is also possible that consistent exposure to the warmer water present in the cooling reservoir allowed fish to acclimate to higher temperatures. This ability of fishes to tolerate higher temperatures in response to increased acclimation temperatures was demonstrated by Ferguson (1958), Cherry et al. (1975, 1977), and Coutant and Carroll (1980).

Mean daily distances moved by walleyes, which ranged from 65.5 m/day in October to 186.8 m/day in June, were considerably less than movement rates reported for walleyes in thermally unaltered lakes and reservoirs (Ager 1976; Holt et al. 1977; Pitlo 1978). However, since the walleyes were not tracked continuously, mobility estimates represent a minimum daily rate. Ross and Winter (1981) reported that walleyes were one of the least mobile (91 m/day) species monitored near a thermal discharge during winter.

In general, seasonal activity patterns exhibited by walleyes were similar to those reported by Schupp (1972), Holt et al. (1977), and Pitlo (1978); with decreasing movement during summer, followed by an increase in movement during fall. The only exceptions to this pattern occurred in June and October when plant operations appeared to play a role in altering walleye activity. In contrast, Ager (1976) observed walleye activity in Center

Hill Reservoir, Tennessee, to be lowest during spring and early summer and highest during winter.

Scott and Crossman (1973) stated that seasonal, as well as daily, movements by walleyes involve a response to temperature or food availability. Although movement patterns exhibited by walleyes in the cooling reservoir coincided with changes in water temperature, it is uncertain whether this was the only variable influencing activity. Schupp (1972) and Holt et al. (1977) explained similar seasonal changes by walleyes in thermally unaltered lakes as responses to availability of forage. Composition and distribution of forage fish in the cooling reservoir, as documented by Wahl (1980) and Henley (1981), indicated a readily available source of food. However, from the information available, it is not known whether this factor played a significant role in regulating walleye movements.

During the summer-fall monitoring period, walleyes established well-defined activity centers. With the exception of walleye studies by Bahr (1977) and Fossum (1975) in the Mississippi River, this type of behavior pattern was in agreement with studies by Ager (1976), Pitlo (1978), Einhouse (1981), and Ross and Winter (1981) in lakes and reservoirs. Although walleyes tracked in the cooling reservoir established relatively large home ranges (36.7-45.9 ha), their activity was limited to the south end of the reservoir. Furthermore, most of this activity was concentrated in specific areas resulting in only a small proportion of the maximum home range being repeatedly used. In comparison, Ross and Winter (1981) observed that during winter, tagged walleyes confined their activity to a relatively small area of a discharge bay (2.2 ha) with 90% of the locations within 100 m of the center of home range. Previous walleye studies have indicated that limitations in the size of occupied areas can result from any number of factors including availability of preferred habitat, social interactions, and/or physical barriers (Holt et al. 1977; Pitlo 1978; Einhouse 1981). In the present study, it was apparent that north to south movement of the warmer discharge water acted as a boundary; limiting the lateral extension of an individuals summer range. By the end of October walleyes began to abandon their summer-fall home range and return to the discharge area.

Habitat utilization in the cooling reservoir was similar to that reported in thermally unaltered lakes and reservoirs. Walleyes exhibited a strong association with steep gradients and rocky substrates. This agrees with the findings of Ager (1976), Kelso (1976b), Pitlo (1978), and Summers (1979). In contrast, Einhouse (1981) reported that walleyes in Chautauqua Lake, New York rarely occurred in areas with steep gradients and firm substrates. He observed most walleyes residing in relatively shallow areas (2.0-4.0 m) near vegetation. In the cooling reservoir, walleyes were primarily located in water 1.0-4.0 m deep. By late summer the fish began to abandon the rocky nearshore areas for deeper water; similar offshore movements were observed by Rawson (1956), Regier et al. (1969), and Pitlo (1978).

Summer distribution and movement of the tagged muskellunge was similar to that reported by Henley (1981). However, the relatively large utilized area, high daily movement, and selection of increased depth by the muskellunge was in contrast to findings by Crossman (1977), Minor and Crossman (1978), and Dombeck (1979). The above studies indicated that summer activity of muskellunge was generally confined to small areas in water less than 2.0 m deep. They also observed reduced movement as temperatures increased. Home range habitat cover in Nogies Creek, Ontario consisted of submergent vegetation, logs, and tree stumps (Minor and Crossman 1978). Muskellunge locations in the cooling reservoir were primarily associated with open-water areas.

Body temperatures of the muskellunge ranged from 20.0° C in May to 27.0° C in July. As summer proceeded, the fish tended to inhabit a progressively narrower temperature range. Maximum temperature associated with muskellunge in Nogies Creek, Ontario was 28.5° C. Dombeck (1979) reported that muskellunge in Moose Lake, Wisconsin were never observed in water less than 21.0° C. He also observed muskellunge in areas with water temperatures in excess of 27.0° C.

Generally, body temperatures were most closely associated with the cooler water temperatures of the surrounding area. Deviations from this pattern occurred during May and July when the muskellunge occasionally occupied the warmer water strata. Although insufficient data during these two periods prohibited conclusive interpretation, it is possible that during July the muskellunge abandoned deeper, cooler regions in response to low dissolved oxygen concentrations.

On 9 July, twelve adult muskellunge, including the tagged fish, were found dead. By 24 July 1981 the die-off had accounted for a total of 59 adult muskellunge. At approximately the same time period during 1980 a similar die-off was observed. Although internal examination indicated muskellunge had not been feeding, all fish appeared in excellent condition. Considering this die-off had occurred during July tends to indicate temperature as the key factor. However, whether muskellunge mortality was related to high water temperature and low dissolved oxygen conditions or to other thermal related synergistic effects is not apparent.

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